
HOW IT WORKS
EARTHQUAKES

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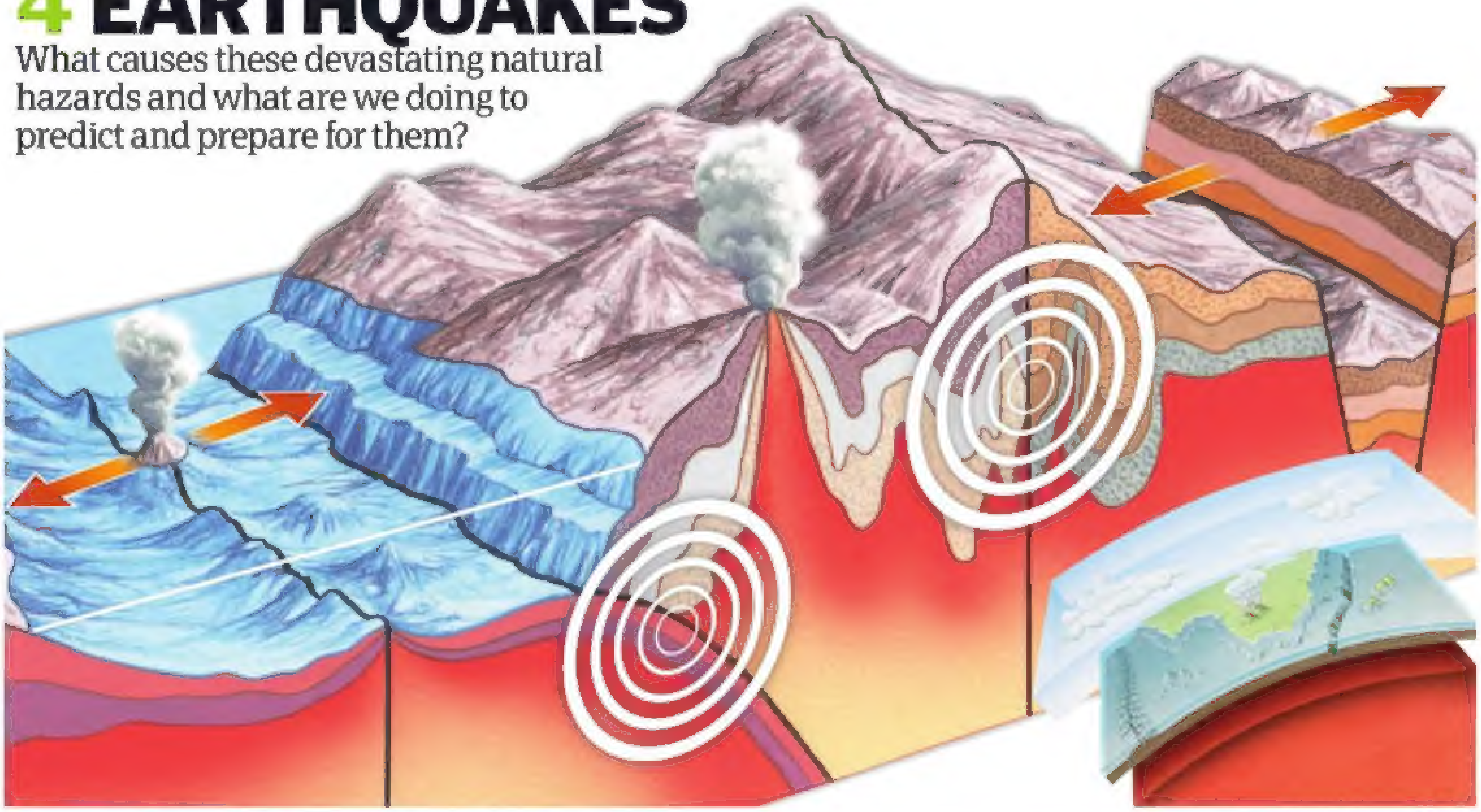
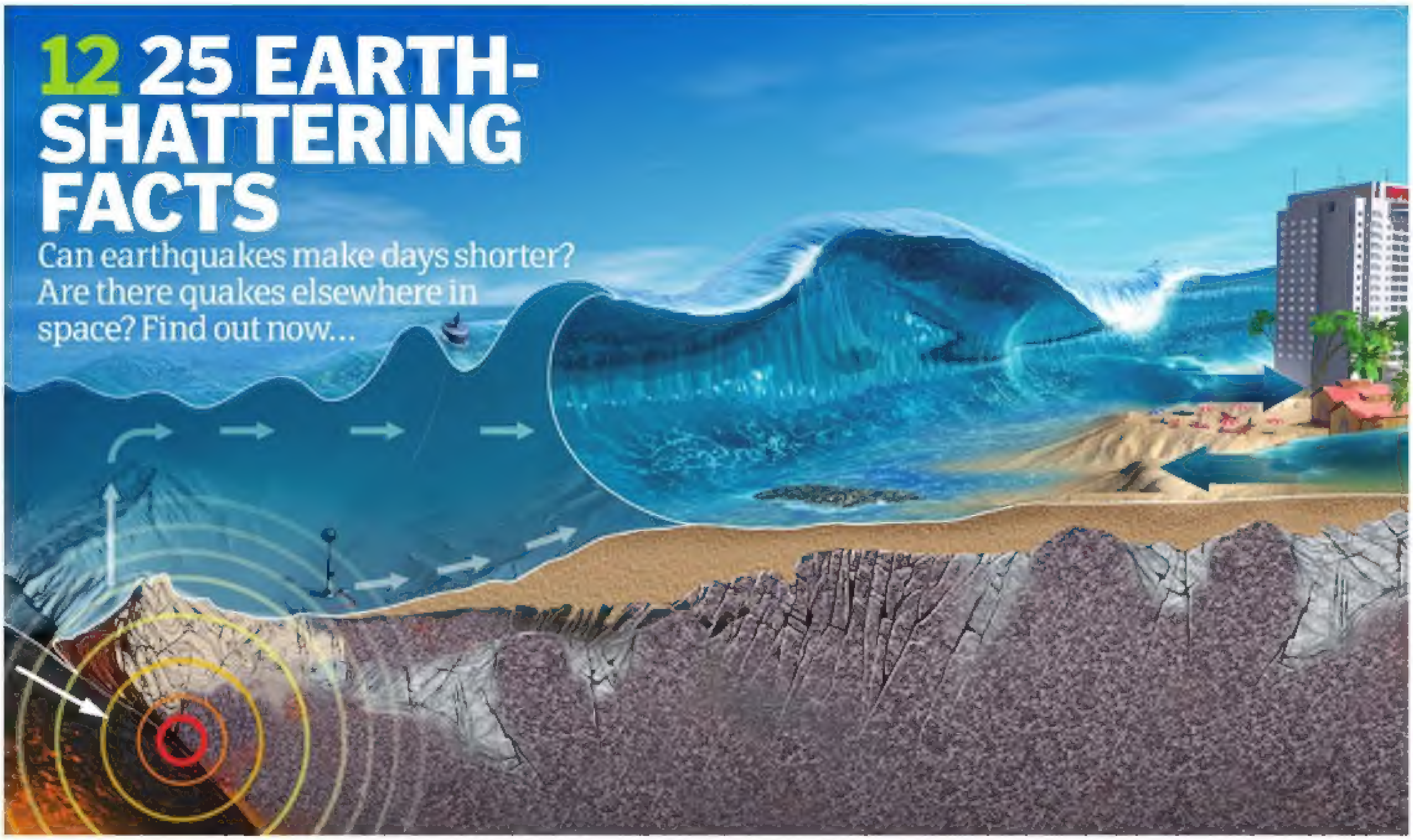




What causes these devastating natural hazards and what are we doing to predict and prepare for them?

Earthquakes are one of our planet's most destructive natural hazards, with the ability to flatten entire cities, trigger enormous tsunamis that wash away everything in their path, and cause a devastating loss of life.

Part of an earthquake's immense power lies in its unpredictability, as a huge quake can strike with very little warning and give those nearby no time to get to safety. Although we do not know when they will occur, we can predict where they are likely to happen, thanks to our knowledge of plate tectonics.

The thin top layer of the Earth, known as the crust, is divided into several plates that are constantly moving. This is caused by heat from the core of the Earth creating convection currents in the mantle just below the crust, which shifts the plates in different directions.

As the plates move, they collide, split apart or slide past each other along the plate boundaries, creating faults where the majority of earthquakes occur. At divergent or constructive plate boundaries the plates are moving apart, causing normal faults that form rift valleys and ocean ridges. When plates move toward each other along convergent or destructive plate boundaries, they create a reverse or thrust fault, either colliding to form mountains or sliding below the other in a process known as subduction. The third type is a conservative or transform plate boundary, and involves the two parallel plates sliding past each other to create a strike-slip fault.

Being able to identify these fault lines tells us where earthquakes are most likely to occur, giving the nearby towns and cities the opportunity to prepare. Although the secondary effects of an earthquake, such as landslides and fires from burst gas lines, can be fatal, the main cause of death and destruction during earthquakes is usually the collapse of buildings. Therefore, particularly in developed parts of the world, structures near to fault lines are built or

Animal inspiration
1 Scientists are trying to mimic the threads that mussels use to stay attached to their shells in order to develop construction materials that are rigid but flexible for absorbing shock.

Invisibility cloak
2 Dubbed the 'seismic invisibility cloak', 100 concentric plastic rings would be buried beneath the foundation of a building and deflect the surface waves around the structure.

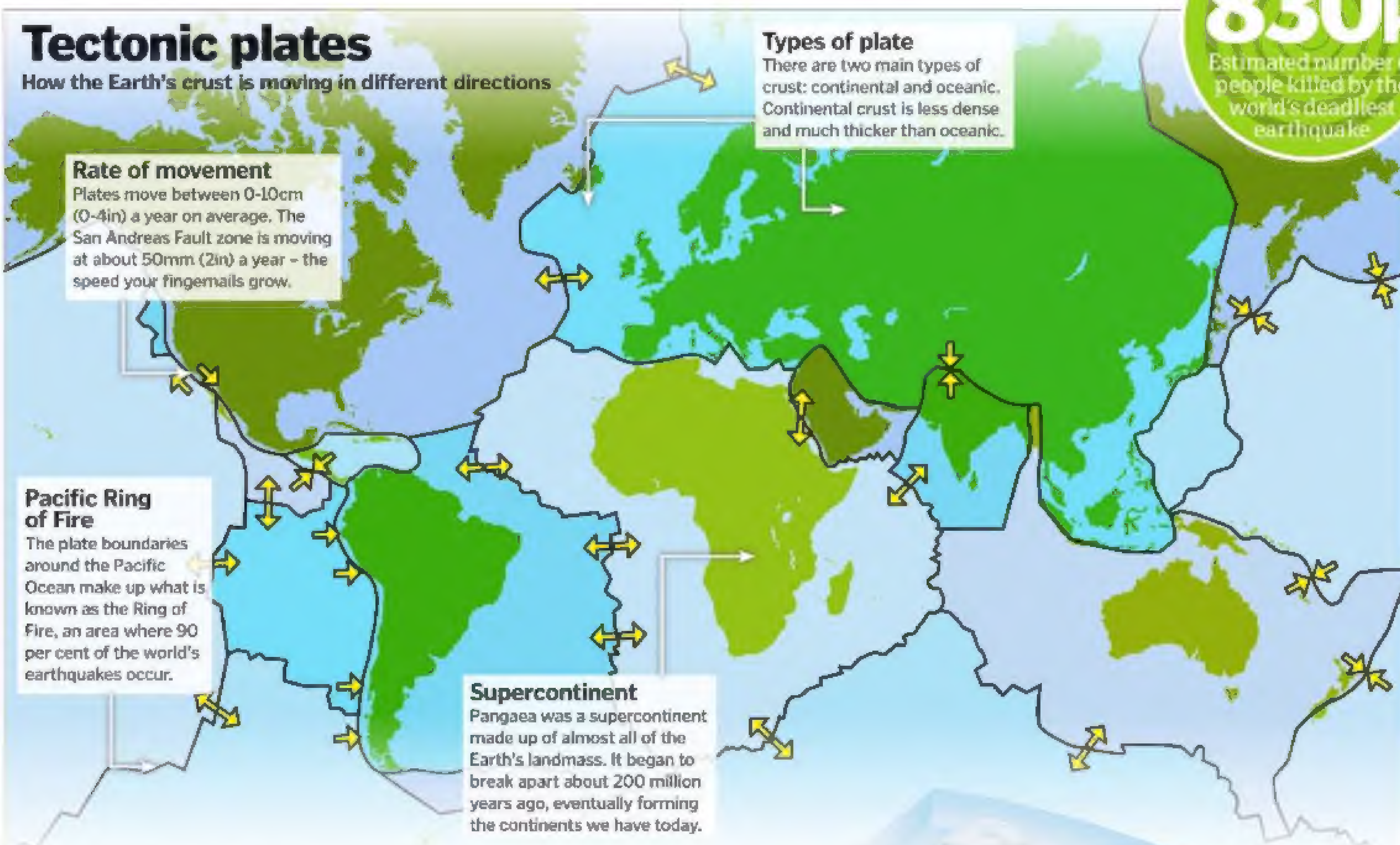
Cardboard constructions
3 Architect Shigeru Ban has designed a church made of 98 giant cardboard tubes reinforced with wooden beams. The cardboard is sturdy but lightweight, so would cause little damage if it collapsed.

Plastic wrap
4 Fiber-reinforced plastic wrap could go around supporting columns in existing buildings. A pressurised adhesive would then be pumped between the column and the wrap.

Smart materials
5 Shape-memory alloys (SMAs) can return to their original shape after experiencing strong forces, so could be used in place of steel and concrete for more resilient buildings.

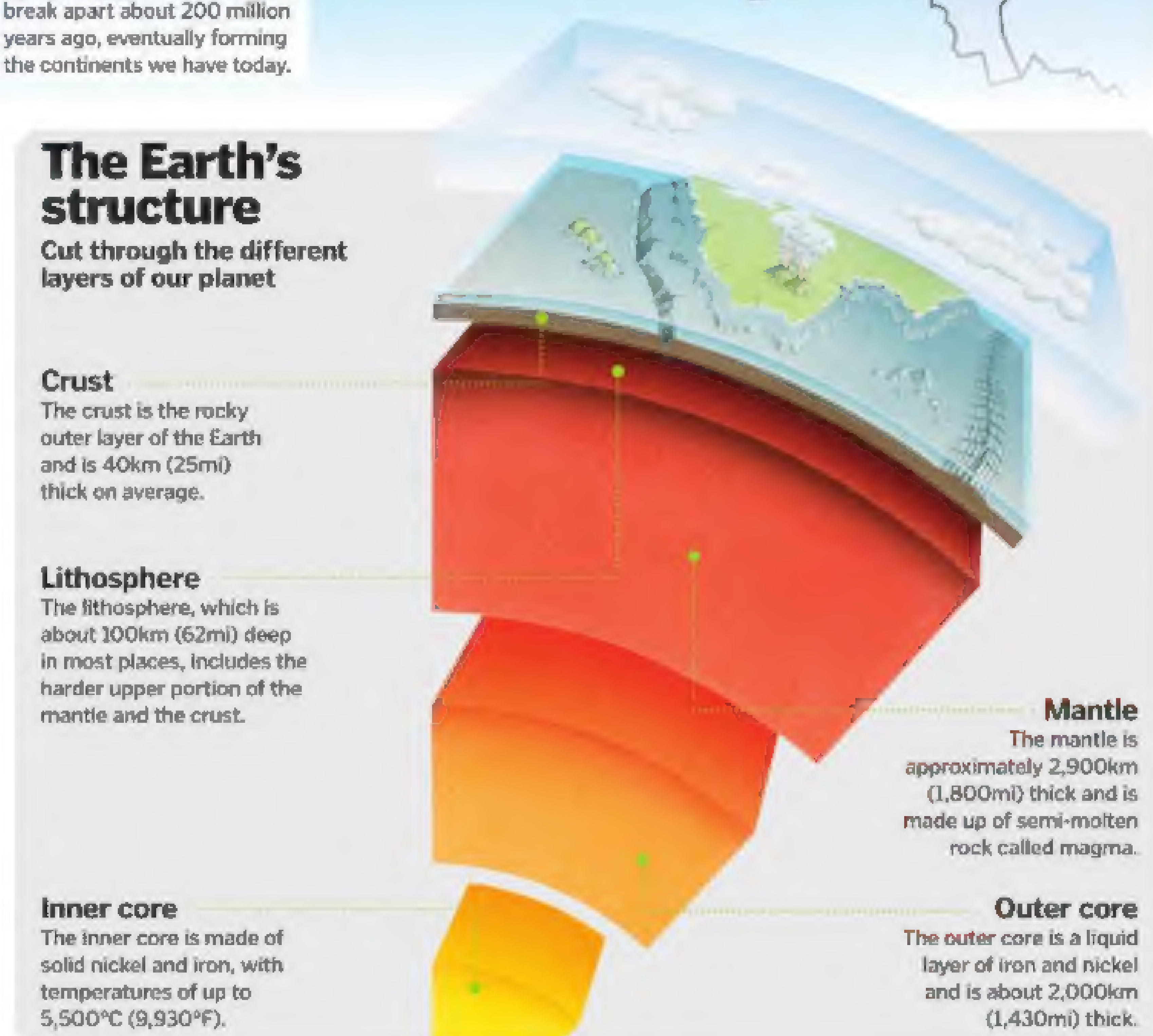
DID YOU KNOW? There are ca 500,000 earthquakes in the world each year, but only 100,000 can be felt – 100 of them cause damage

830k
Estimated number of people killed by the world's deadliest earthquake



adapted to withstand violent shock waves. The surrounding population will usually carry out regular earthquake drills, such as The Great California ShakeOut, that gives people a chance to practise finding cover when a quake hits. Unfortunately, many poorer areas cannot afford to be so well prepared, and so when an earthquake strikes, the resulting destruction is often even more devastating and the death toll is usually much higher.

However, our knowledge of how earthquakes work and the development of new technologies are helping us to find potential methods for predicting when the next one will strike. Scientists can currently make general guesses about when an earthquake may occur by studying the history of seismic activity in the region and detecting where pressure is building along fault lines, but this only provides very vague results so far. The ultimate goal is to be able to reliably warn people of an imminent earthquake early enough for them to prepare and minimise the loss of life and property. Until then, being under the constant threat of an impending earthquake is unfortunately part of everyday life for those living along the Earth's constantly active fault lines.



"Underwater earthquakes can sometimes trigger enormous destructive waves called tsunamis"

Anatomy of an earthquake

How earthquakes are caused and shake the ground beneath our feet

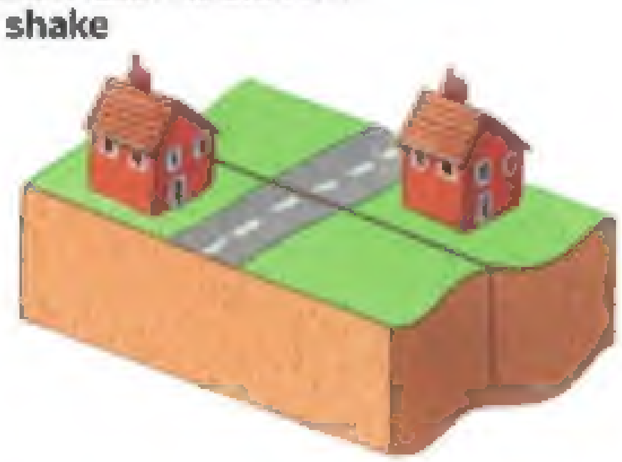
Earthquakes are caused by the build-up of pressure that is created when tectonic plates collide. Eventually the plates slip past each other and a huge amount of energy is released, sending seismic waves through the ground. The point at which the fracture occurs is often several kilometres underground and is known as the focus or hypocentre. The point directly above it on the surface is the epicentre, and this is where most of the damage is caused. Earthquakes have different characteristics depending on their type of fault line, but when they occur underwater, they can sometimes trigger enormous destructive waves called tsunamis.

How earthquakes occur

The build-up of pressure that causes the ground to move and shake

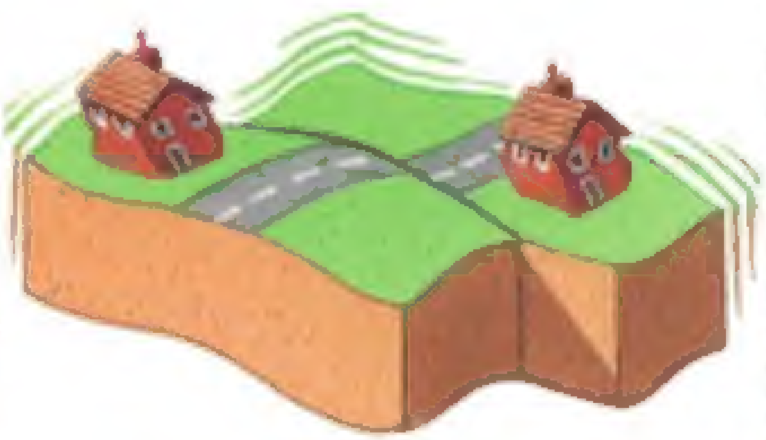
Friction causes pressure

As the tectonic plates are pushed past or into each other, friction prevents them from moving and causes a build-up of immense pressure.



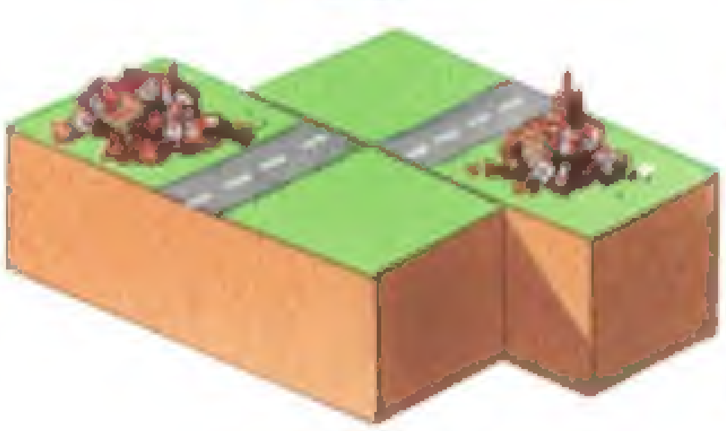
Energy is released

When the pressure finally overcomes the friction, the plates will suddenly fracture and slip past each other, releasing energy and causing seismic waves.



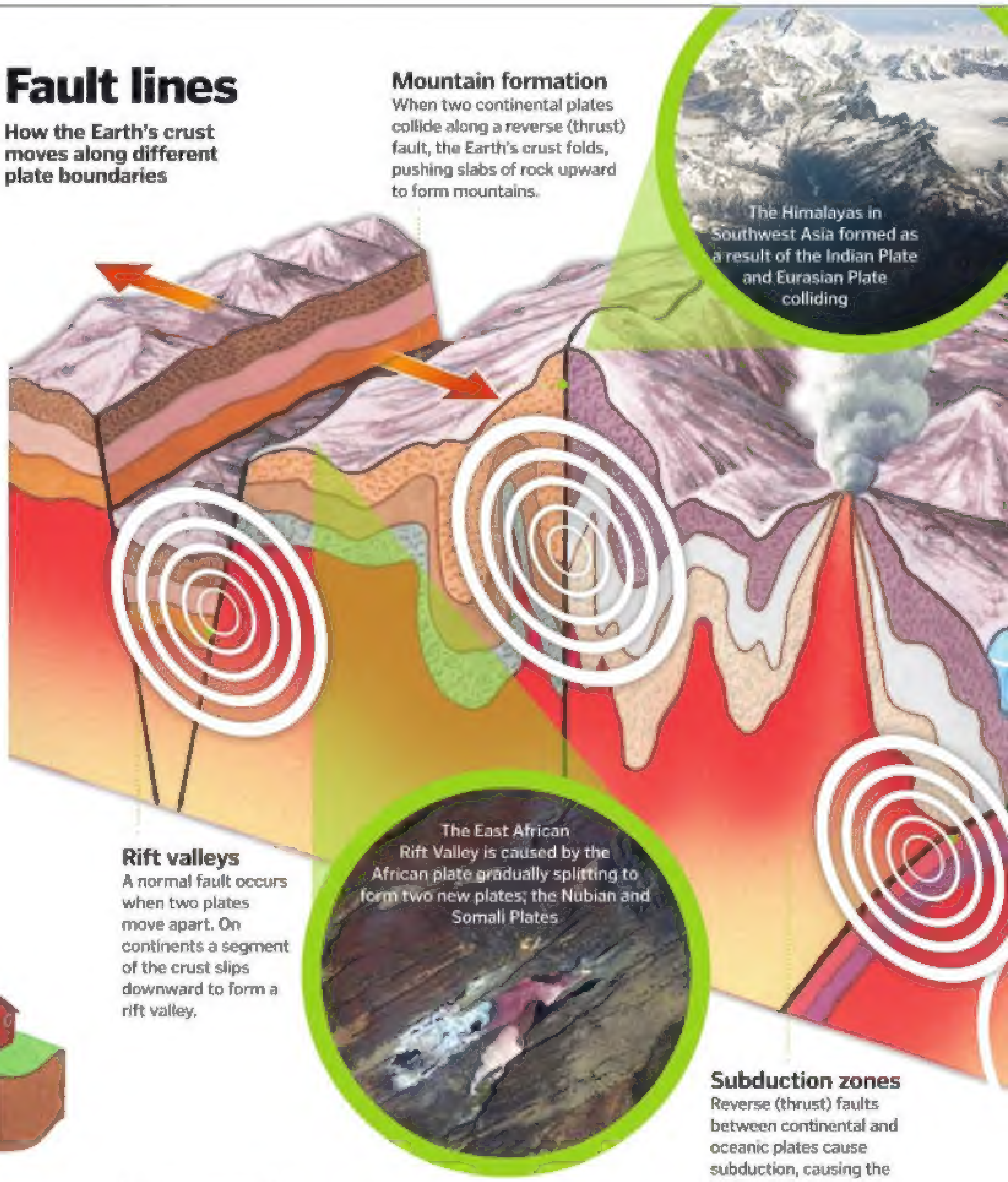
The process starts again

Once the energy has been released, the plates will assume their new position and the process will begin all over again.



Fault lines

How the Earth's crust moves along different plate boundaries



Mountain formation

When two continental plates collide along a reverse (thrust) fault, the Earth's crust folds, pushing slabs of rock upward to form mountains.

Rift valleys

A normal fault occurs when two plates move apart. On continents a segment of the crust slips downward to form a rift valley.

Subduction zones

Reverse (thrust) faults between continental and oceanic plates cause subduction, causing the higher-density oceanic plate to sink below the continental plate.

Tsunamis

How underwater earthquakes trigger enormous and devastating waves

Water displacement

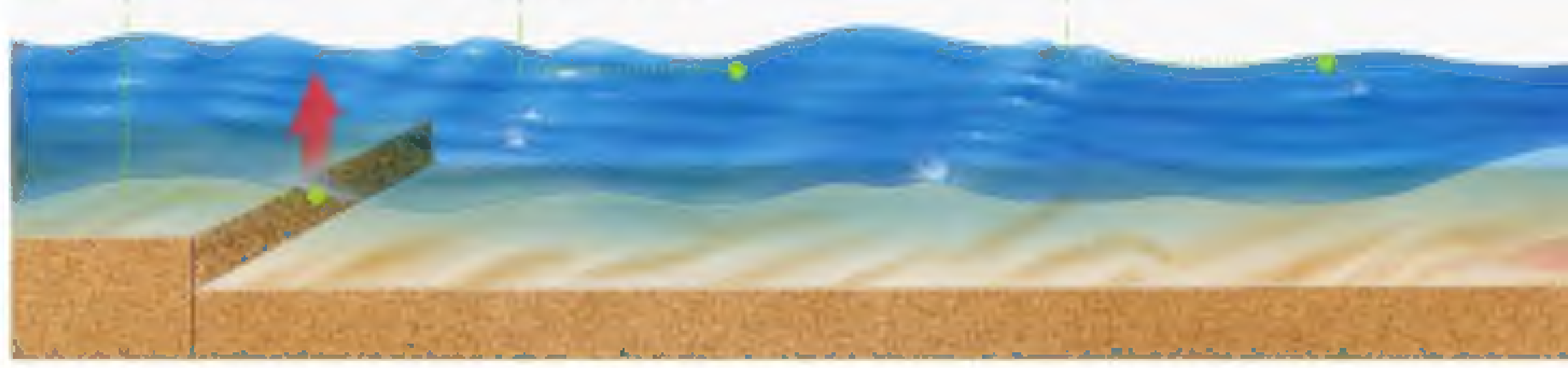
As two oceanic plates slip past each other and cause an earthquake, a huge amount of water above it is displaced.

Small beginnings

Small, rolling waves begin to spread outward from the earthquake's epicentre at speeds of up to 805km/h (500mph).

Tsunami in disguise

The tsunami's long wavelength and small wave height – usually less than 1m (3.3ft) – means that it blends in with regular ocean waves.



RECORD BREAKERS
BIG TREMOR

9.5

MOST POWERFUL EARTHQUAKE

The largest earthquake ever recorded happened on 22 May 1960 in southern Chile. It was caused by the subduction of the Nazca Plate under the South American Plate.

DID YOU KNOW? *Tsunamis and tidal waves are different things as the latter is caused by gravitational activity, not earthquakes*

Ocean ridges
When a normal fault occurs between two oceanic plates, new magma rises up to fill the gap and creates ocean ridges.

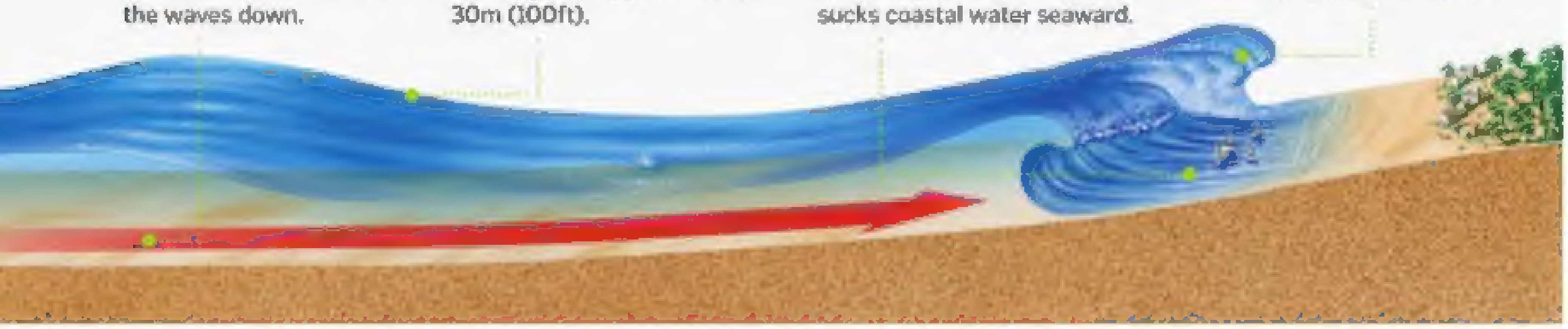
Strike-slip faults
When two plates slide past each other horizontally, this is known as a strike-slip or transform fault.

Starting to slow
As they reach the shallower waters of the coast, the rising sea floor causes friction that slows the waves down.

Waves begin to grow
As they slow down, the wavelengths begin to shorten, causing the tsunami to grow to a height of approximately 30m (100ft).

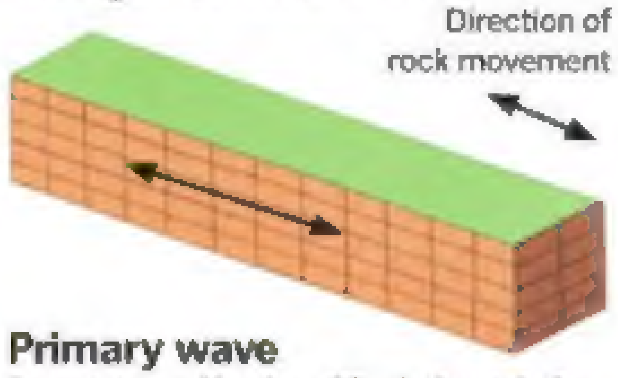
Early warning
A tsunami's trough, the low point beneath the wave's crest, often reaches shore first, producing a vacuum effect that sucks coastal water seaward.

The tsunami strikes
A few minutes later, the tsunami's crest will hit the shore followed by a series of more waves, called a wave train.

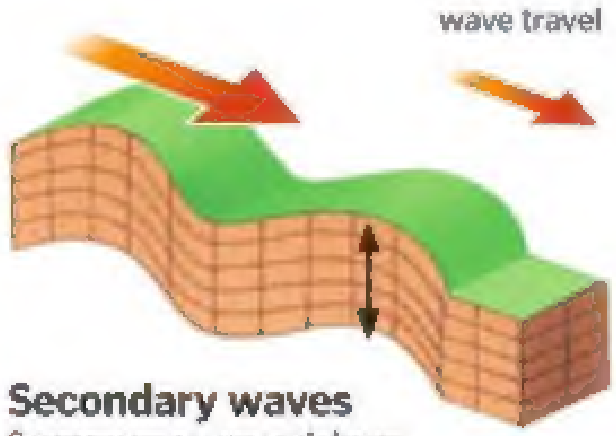


Earthquake waves

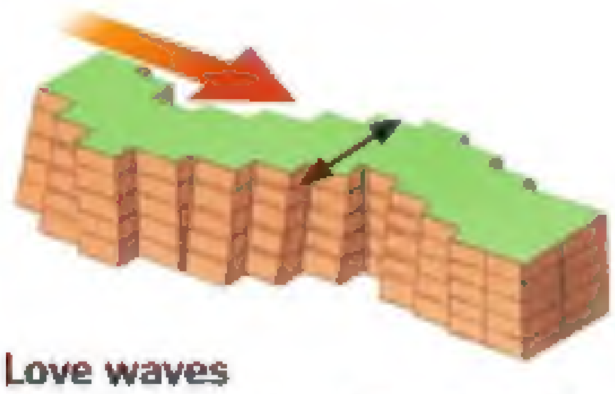
How seismic waves travel through the Earth's crust



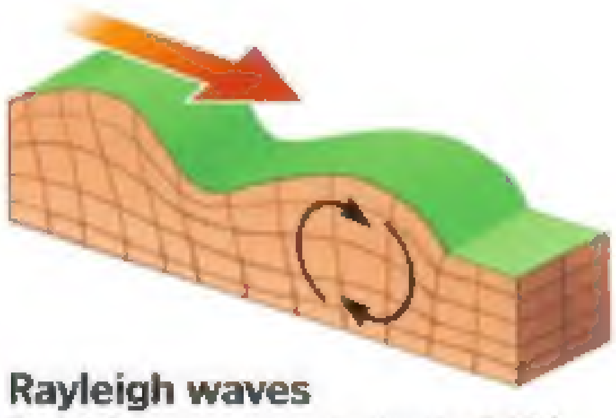
Primary wave
P waves travel back and forth through the Earth's crust, moving the ground in line with the wave. They are the fastest moving of the waves, travelling at about 6-11km/s (3.7-6.8mi/s) , and so typically arrive first with a sudden thud.



Secondary waves
S waves move up and down, perpendicular to the direction of the wave, causing a rolling motion in the Earth's crust. They are slower than P waves, travelling at about 3.4-7.2km/s (2.1-4.5mi/s), and can only move through solid material, not liquid.



Love waves
Unlike P and S waves, surface waves only move along the surface of the Earth and are much slower. Love waves, named after the British seismologist AEH Love, are the faster of the two types and shake the ground side to side, perpendicular to direction of the wave.



Rayleigh waves
Rayleigh waves, named after the British physicist Lord Rayleigh, are surface waves that cause the ground to shake in an elliptical motion. Surface waves arrive last during an earthquake but often cause the most damage to infrastructure due to the intense shaking they cause.

"Early-warning systems give people a few seconds or minutes to prepare before the earthquakes hit"

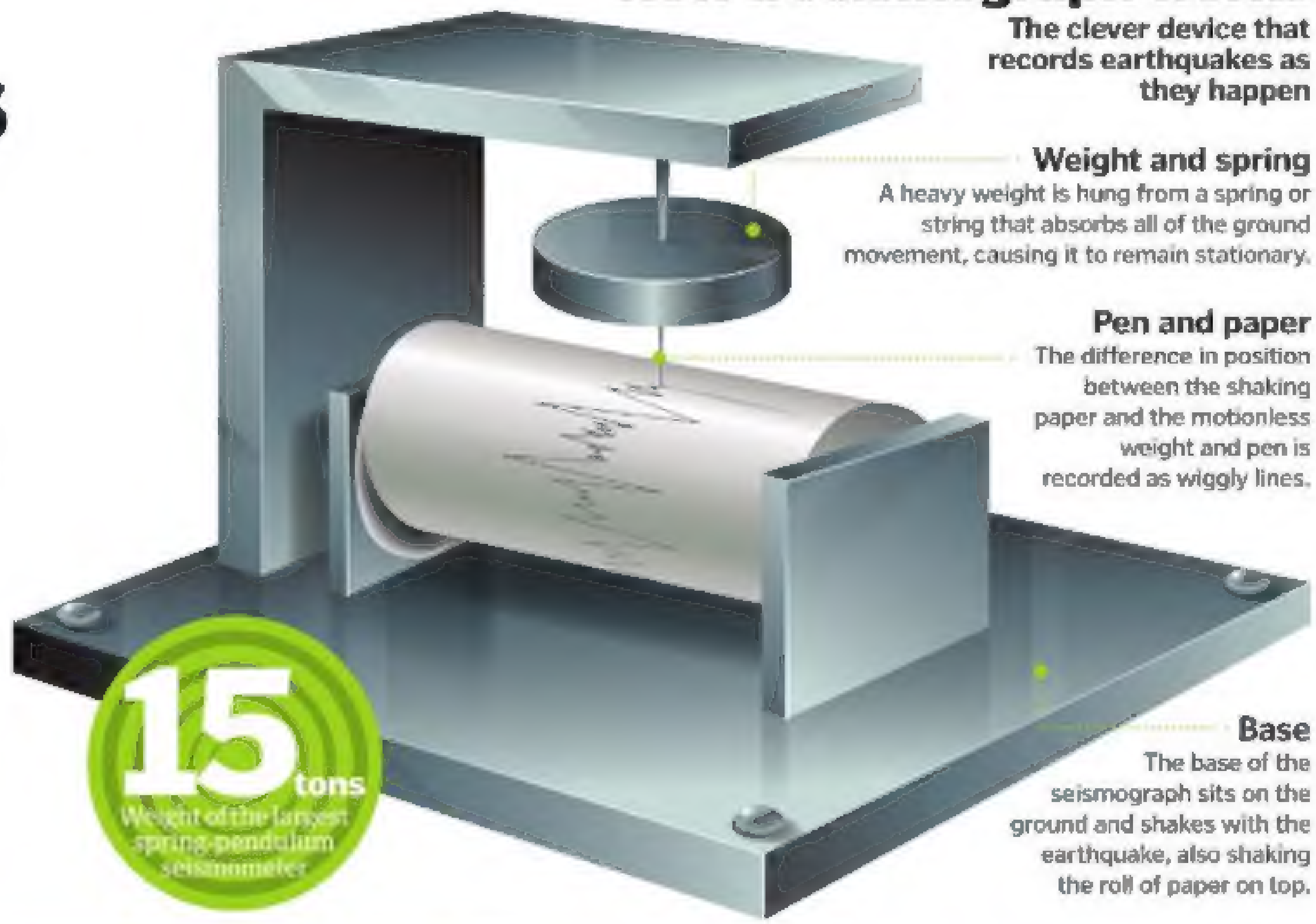
Monitoring earthquakes

Earthquake-recording methods of the past and present

Earthquakes are measured using an instrument called a seismograph, which produces a visual record of tremors in the Earth's crust. This shows the seismic waves of the earthquake as a wiggly line, allowing you to plot the different waves types. The small but fast P waves appear first, followed by the larger but slower S waves and surface waves. The amount of time between the arrival of the P and S waves shows how far away the earthquake was, allowing scientists to work out the exact location of the epicentre. The size of the waves also helps them determine the magnitude or size of the earthquake, which is measured using the Richter Scale.

How a seismograph works

The clever device that records earthquakes as they happen

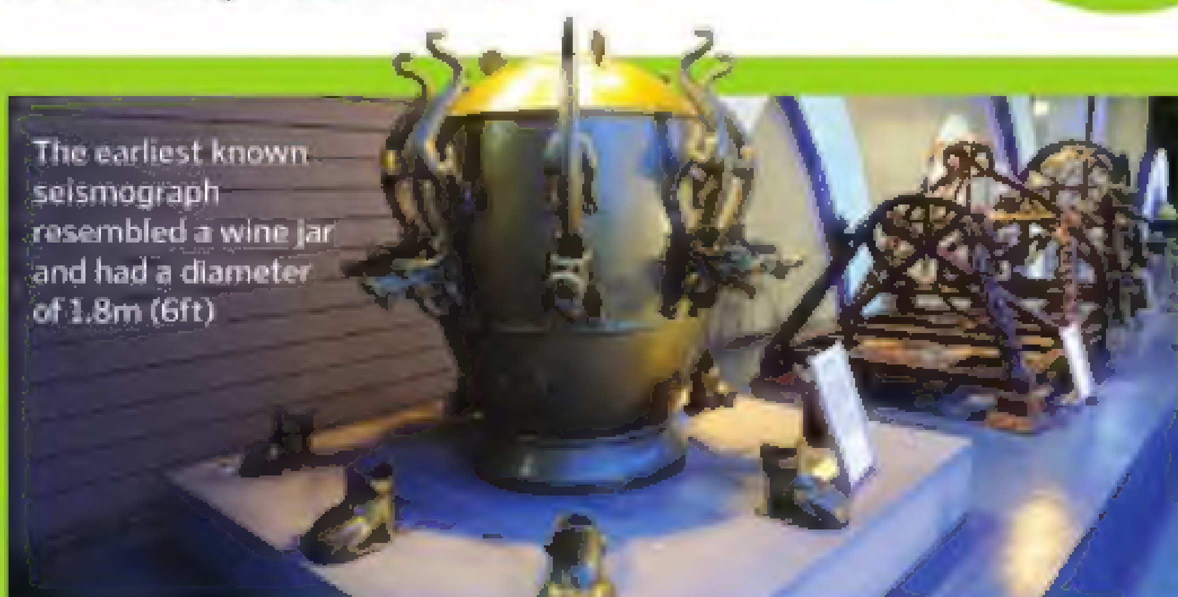


Weight and spring
A heavy weight is hung from a spring or string that absorbs all of the ground movement, causing it to remain stationary.

Pen and paper
The difference in position between the shaking paper and the motionless weight and pen is recorded as wiggly lines.

Base
The base of the seismograph sits on the ground and shakes with the earthquake, also shaking the roll of paper on top.

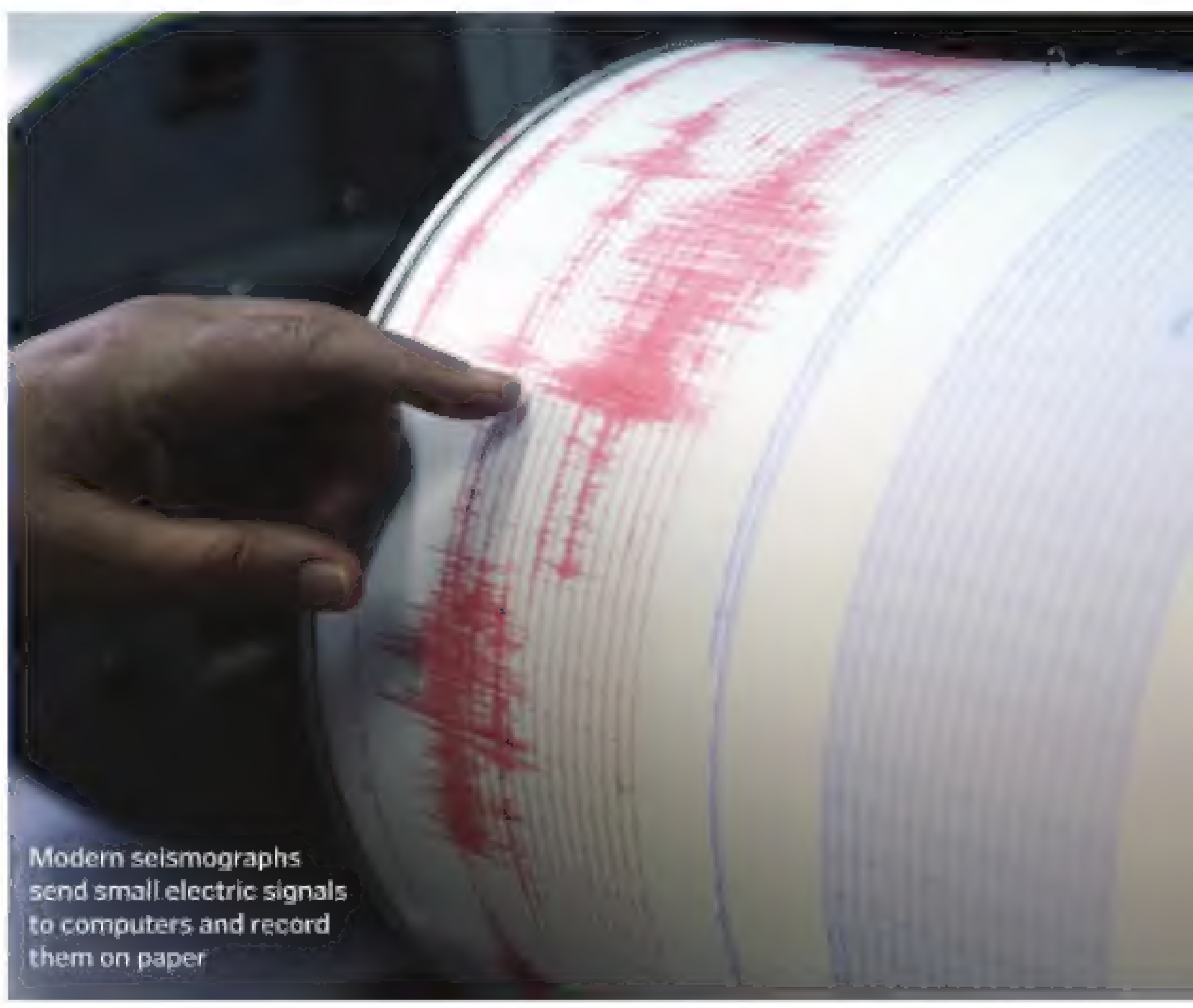
15 tons
Weight of the largest spring-pendulum seismometer



The earliest known seismograph resembled a wine jar and had a diameter of 1.8m (6ft)

The first seismograph

The earliest known seismoscope was invented by Chinese philosopher Chang Héng in 132. It didn't actually record ground movements, but simply indicated that an earthquake had hit. The cylindrical vessel had eight dragon heads around the top, facing the eight principal directions of the compass, each with an open-mouthed toad underneath it. Inside the mouth of each dragon was a ball that would drop into the mouth of the toad below when an earthquake occurred. The direction of the shaking could be determined by which dragon released its ball. It is not known what was inside the vessel, but it is thought that some kind of pendulum was used to sense the earthquake and activate the ball in the dragon's mouth. The instrument reportedly detected a 650-kilometre (373-mile)-distant earthquake which was not felt by people at the location of the seismoscope.



Modern seismographs send small electric signals to computers and record them on paper

The Richter Scale

Measuring the magnitude of earthquakes using US seismologist Charles F Richter's system

0-2.9
There are more than 1 million micro earthquakes a year but they are not felt by people.

3.0-3.9
Minor earthquakes are felt by many people but cause no damage – there are as many as 100,000 of these a year.

4.0-4.9
Felt by all, light earthquakes occur up to 15,000 times a year and cause minor breakages.

5.0-5.9
A moderate earthquake causes some damage to weak structures. There are around 1,000 of them a year.

DID YOU KNOW? *The earliest recorded evidence of an earthquake has been traced back to 1831 BCE in China's Shandong province*

Laser beams are used to detect small movements of the ground in Parkfield, California

With a little bit of warning, people can hide under tables and desks to protect them from falling debris in an earthquake

Predicting earthquakes

Modern methods that could help us plot future seismic activity

Currently, earthquakes cannot be predicted far enough in advance to give people much notice, but there are some early warning systems in place to give people a few seconds or minutes to prepare before the serious shaking starts. When seismometers detect the initial P waves, which don't usually cause much damage, they can estimate the epicentre and magnitude of the earthquake and alert the local population before the more destructive S waves arrive. Depending on their distance from the epicentre, people should then have just enough time to take cover, stop transport and shut down industrial systems in order to reduce the number of casualties.

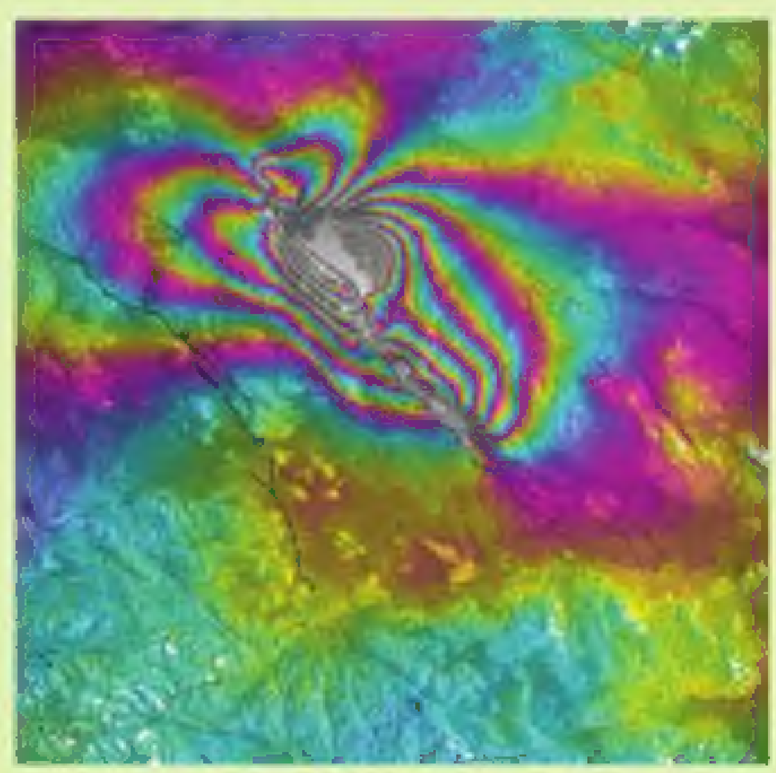
Scientists are also enlisting the help of the general public to help them develop early warning systems. The Quake-Catcher Network (QCN) is a worldwide initiative supplying people with low-cost motion sensors that they can fasten to the floor in their home or workplace. These sensors are then connected to their computer and send real-time data about seismic activity to the QCN's servers, with the hope that earthquake warnings can be issued when strong motions are detected in any of these.

To be able to predict earthquake further in advance, a characteristic pattern or change that precedes each earthquake needs to be identified. One suggestion is that increased levels of radon gas escape from the Earth's crust before a quake, however this can also occur without being followed by seismic activity, so does not provide conclusive evidence of a earthquake.

Scientists are even trying to determine whether animals can predict earthquakes better than we can, but no widespread unusual behaviour has been linked to earthquakes. Other potential earthquake-predicting methods are being tested in Parkfield, California along the San Andreas fault. Among other things, scientists are using lasers to detect the movement of the Earth's crust, sensors to monitor groundwater levels in wells, and a magnetometer to measure changes in the Earth's magnetic field, all with the hope that this will allow them to predict the next big quake.

Radar mapping

One of the more recent developments in earthquake monitoring is interferometric synthetic aperture radar (InSAR). Satellites, or specially adapted planes, send and receive radar waves to gather information about the features of the Earth. The reflected radar signal of a fault line is recorded multiple times to produce radar images, which are then combined to produce a colourful interferogram (below). Each colour shows the amount of ground displacement that has occurred between the capturing of each image, mapping the slow warping of the ground surface that leads to earthquakes. This technique is sensitive enough to detect even tiny ground movements, allowing scientists to monitor fault lines in more detail and detect points where immense pressure is building up. It is hoped that this data will eventually enable scientists to tell when this pressure has reached a hazardous level, leading to more reliable earthquake predictions that give the public days or even weeks to prepare.



6.0-6.9

Over 100 strong earthquakes happen each year, causing moderate damage in populated areas.

7.0-7.9

A loss of life and serious damage over large areas are the result of major earthquakes that happen around ten times a year.

8.0 & higher

There are fewer than three earthquakes classed as 'great' each year, but they cause severe destruction and loss of life over large areas.

"The Pacific Ring of Fire rarely knows a moment's peace, playing host to 90 per cent of the world's earthquakes"

A century of earthquakes

How does this seismographic map illustrate the volatile nature of the Pacific Ring of Fire?

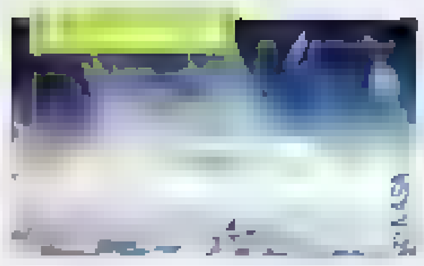
The coastline along the Pacific Ocean has long been known to be an area of intense seismic activity. Violent volcanic eruptions ravage the far east, while earthquakes are prolific either side of the International Date Line. This 40,000-kilometre (25,000-mile), horseshoe-shaped area around the coast stretching from New Zealand, along Indonesia and Japan, past Russia, across the Bering Strait and right down the west coast of the Americas then back across Antarctica, is known as the Pacific Ring of Fire. It rarely knows a moment's peace, playing host to 90 per cent of the world's earthquakes – and 84 per cent of the planet's biggest earthquakes, a product of multiple plates colliding, slipping over and subducting under one another in a giant, non-stop game of tectonic Twister.

Since Thomas Gray, James Alfred Ewing and John Milne invented the modern seismometer in the late-19th century, activity has been carefully recorded in this region. But it's only since the Sixties that scientists have adopted a more methodical approach to detailing tectonic dynamics – and there have literally been millions of earthquakes recorded since, though few have been worthy of note. Over 70 per cent of the earthquakes in this image have been a relatively 'puny' magnitude 4.0 (equivalent to the tremors created by 15 tons of TNT exploding), less than two per cent have been a considerable magnitude 6.0 (15 kilotons) and just 0.01 per cent have been a mighty magnitude 8.0 (ie 15 megatons) or above.

In this illustration, you can see many of the last century's most famous earthquakes. These include the magnitude 8.5 Indonesian quake in the Banda Sea that caused huge tsunamis in 1938; the famous magnitude 7.9 earthquake that practically razed San Francisco in 1906; and the biggest-ever recorded earthquake, the magnitude 9.5 monster whose epicentre shook southern Chile to pieces in 1960.

Valdivia earthquake

[illegible] biggest on record, the seismic equivalent of [illegible]



Chicxulub impact

It's estimated that the [illegible] would have registered magnitude [illegible] Earth 65 million years ago

Magnetar SGR 1806-20

This behemoth happened in 2004 [illegible] light years away – but at magnitude [illegible]

Creating the earthquake map

In essence, creating this chart was a fairly simple but painstaking process. John Nelson and the team at data visualisation company IDV Solutions compiled data from the Advanced National Seismic System (ANSS) – a catalogue of millions of recorded earthquakes since 1898 – and sorted them by intensity. Earthquakes of magnitude 4.0 through to 8.0+ were given a green dot and placed according to the epicentre, with brighter dots representing stronger seismic events. The resulting blur of green highlights the volatility of the Pacific Ring of Fire, with the most powerful earthquakes visible as distinct pinpoints of intense green-yellow.

"The volcanic island chain of Indonesia probably experiences the most earthquakes based on landmass"

25 EARTH SHATTERING FACTS

1. What's the deepest epicentre on record?
750km

2. Do more earthquakes occur in hot weather?
No

Can earthquakes make days shorter? Are there quakes elsewhere in space? Find out now…

The earthquake and tsunami that devastated north-east Japan in March 2011 demonstrate the terrifying power of these natural phenomena. Almost 16,000 people died and more than a million buildings wholly or partly collapsed.

A year after the event, 330,000 people were still living in hotels or in other temporary accommodation, unable to return home. A further 3,000 people were still listed as missing. The gigantic tsunami waves spawned by the earthquake inundated the power supply and cooling of three reactors at the Fukushima Daiichi power station. The subsequent nuclear accident – the worst since Chernobyl – caused worldwide panic.

Earthquakes are unstoppable and strike with little or no warning, but we know a growing amount about how they work. Scientists have developed networks of sensors for monitoring ground movements, changes in groundwater and magnetic fields, which may indicate an impending quake. Engineers, meanwhile, have created new forms of architecture to resist earthquakes when they do strike. So without further ado, let's learn some earth-shattering facts…

5 TOP FACTS QUAKE PROOFING

Cloaking device
1 A cloak of concentric plastic rings could protect future buildings from quakes. Waves of vibrations would be diverted in an arc around the building, saving it from damage.

Get braced
2 Engineers strengthen buildings against twisting forces by building around a skeleton of diagonal crossbeams, vertical shear walls and steel frames.

Steeling up
3 Buildings made of structural steel or reinforced with steel beams are less brittle than unreinforced brick or concrete buildings, and can flex when swayed by an earthquake.

Rubber feet
4 The building sits on lead-rubber cylinders, bearings or springs. These sway horizontally when a quake hits to reduce the sideways movement of the structure.

Symmetry
5 Box-shaped buildings are more resistant than irregular-shaped ones, which twist as they shake. Each wing of an L or T-shaped building may vibrate separately, increasing damage.

[illegible]

3. What is Earth's crust made of?

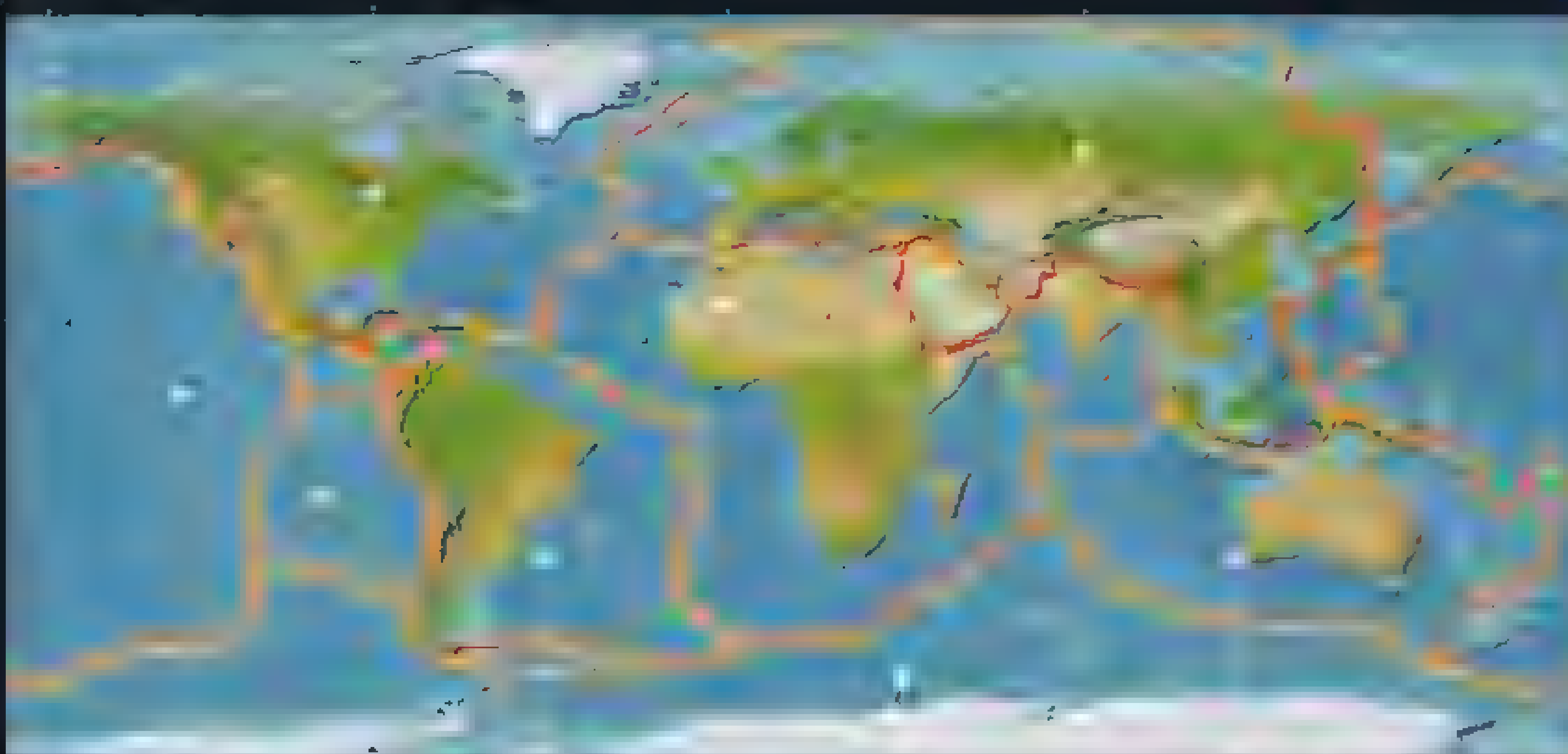
The crust consists of rock broken into moving slabs, called plates. These plates float on the denser rocks of the mantle, a sticky layer lying between the planet's core and the crust. Granite is the commonest rock in the crust that makes up Earth's continents. This continental crust is an average 35 kilometres (22 miles) thick, deepest beneath mountain ranges. Ocean floor crust is thinner – on average six kilometres (four miles) – and mainly made of denser volcanic rocks, such as basalt. Granite is 73 per cent oxygen and silicon. Basalt is denser as the silicon is contaminated with heavier elements like iron.

Pacific Plate
Earth's biggest plate is among the fastest moving, travelling north-west some seven centimetres (three inches) annually.

North American Plate
The continent of North America and some of the Atlantic Ocean floor sit on this plate.

African Plate
This plate carrying the African continent carries some of the world's most ancient crust – up to 3.6 billion years old.

Eurasian Plate
The Himalayas, Earth's highest mountain range, is rising as the Indian Plate thrusts beneath the Eurasian Plate.



Nazca Plate
The Nazca Plate located off South America's west coast is one of several smaller plates.

South American Plate
The collision of South America with the Nazca Plate is lifting up the Andes, our planet's longest mountain range.

Antarctic Plate
Until 45 million years ago, the Antarctic Plate was joined to the Australian Plate.

Indo-Australian Plate
The Indo-Australian Plate may be splitting apart to form separate Indian and Australian Plates.

4. Did the 2011 quake in Japan shorten the days on Earth?

Yes, but you're unlikely to notice. Every day is now 1.8 microseconds shorter, according to NASA. The Japan earthquake made Earth spin slightly faster by changing its rotation around an imaginary line called the figure axis. The Earth's mass is balanced around the figure axis, and it wobbles as it spins. That wobble naturally changes one metre (3.3 feet) a year due to moving glaciers and ocean currents. The 2011 Tohoku earthquake moved the ocean bed near Japan as much as 16 metres (53 feet) vertically and 50 metres (164 feet) horizontally – that's the equivalent horizontal distance to an Olympic swimming pool! The shifting ocean bed increased Earth's wobble around the figure axis by 17 centimetres (6.7 inches). As the wobble grew, Earth sped up its rotation. It's the same principle as when a figure skater pulls their arms closer to their body in order to spin faster.

5. What is the shadow zone of an earthquake?

A shadow zone is the location on the Earth's surface at an angle of 104-140 degrees from a quake's origin that doesn't receive any S-waves or direct P-waves. S and P-waves are seismic waves that can travel through the ground. Seismic waves are shockwaves created when a fault suddenly moves. The shadow zone occurs as S-waves can't pass through the Earth's liquid outer core, while P-waves are refracted by the liquid core.

6. Where is the quake capital?

Around 90 per cent of earthquakes occur on the so-called Ring of Fire, a belt of seismic activity surrounding the Pacific Plate. The Ring of Fire is a massive subduction zone where the Pacific Plate collides with and slides beneath several other crustal plates. Most earthquakes are measured in Japan, which lies on the Ring of Fire at the junction of the Pacific, Philippine, Eurasian and Okhotsk Plates. Japan has a dense earthquake-monitoring network, which means scientists can detect even small quakes. The volcanic island chain of Indonesia probably experiences the most earthquakes based on landmass, however it has fewer instruments for measuring them.

7. Are earthquakes more likely to occur in the morning? No

8 [illegible] another word for an earthquake. It's also another [illegible]

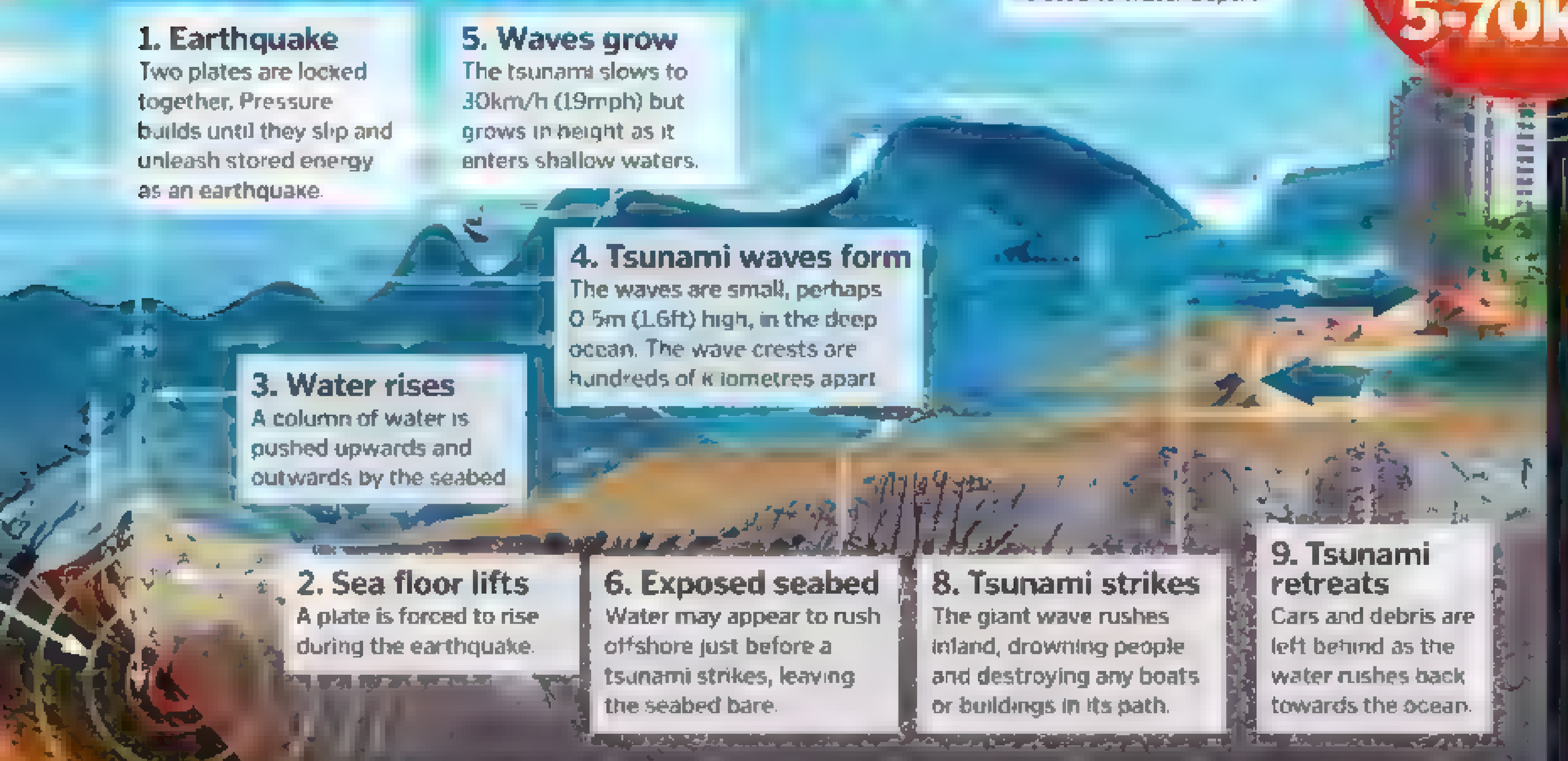
9 How can scientists tell how far away an earthquake occurred?
[illegible] they can calculate the [illegible]

10 What's the earliest recorded major earthquake in history?
The first earthquake [illegible] than data recorded today

11 What do the lines on a seismometer reading represent?
[illegible]

> "Seismometers on the Moon detected tidal 'moonquakes' caused by the pull of the Earth's gravity"

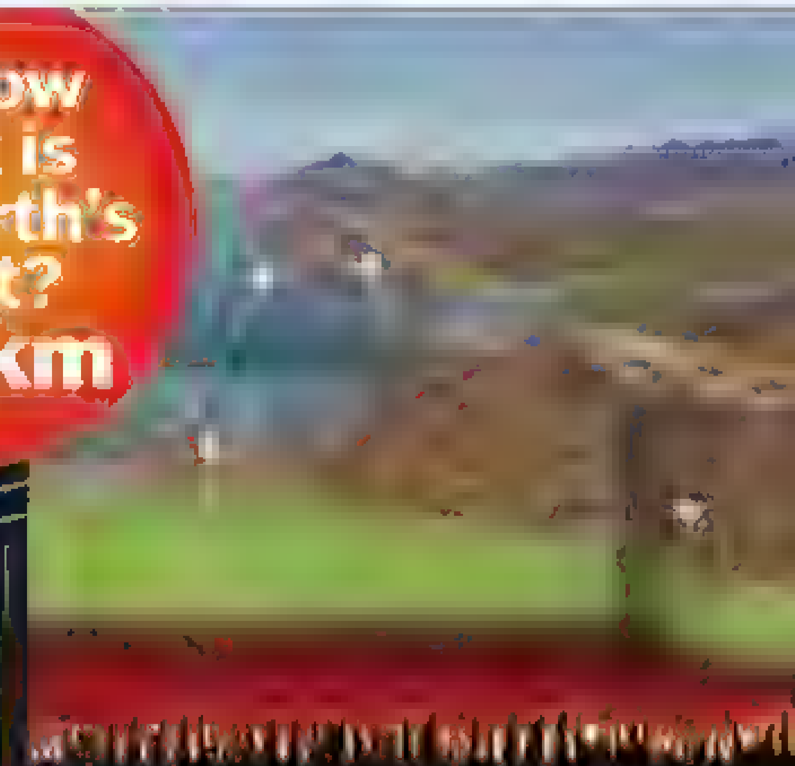
12. Why do quakes at sea lead to tsunamis?



Earthquakes trigger tsunamis by generating ripples, similar to the effect of sloshing water in a glass. Tsunamis are giant waves, which can cross oceans at speeds similar to jet aircraft, up to 700 kilometres (435 miles) per hour, and reach heights of 20 metres (66 feet) as they hit the coast. They sweep inland faster than running speed, carrying away people and buildings alike. For example, the 2004 Indian Ocean tsunami claimed 300,000 lives and made nearly 2 million more homeless.

15. How thick is the Earth's crust?

5-70km



Oceanic crust
The Pacific Plate is mainly oceanic crust, which is younger and thinner than continental crust – about 5-10km (3-6mi) thick

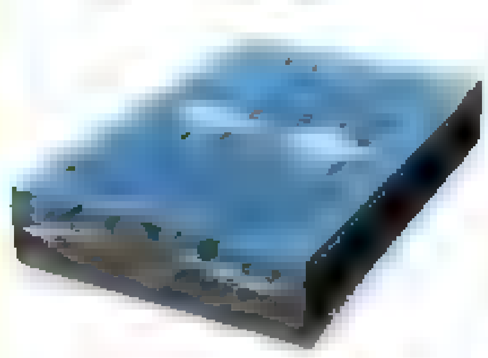
San Andreas Fault
The San Andreas is a strike-slip fault created by the Pacific and North American Plates sliding past each other

16. How many quakes occur each year?

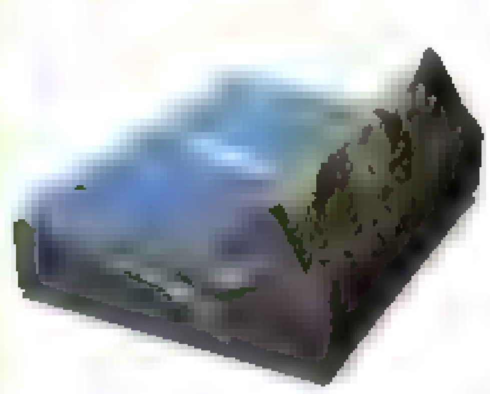
500,000

13. Are there different types of earthquake?

Strike-slip fault
Roads can be sheared apart along strike-slip faults. They're straight cracks in the crust where two plates are sliding horizontally past each other. Every time a section of the fault moves, an earthquake occurs



Normal fault
Earth's brittle crust becomes fractured along fault lines. Quakes occur along a normal fault when the two sides move apart. Rock slabs sitting above the fault slide down in the direction the plates are moving, like at the Mid-Atlantic Ridge



Thrust fault
The 2011 Tohoku quake ruptured a thrust fault in a subduction zone. These zones are associated with Earth's most violent quakes as oceanic crust grinds beneath continental crust, creating great friction. Huge stresses can build here and release the same energy as a thousand hydrogen bombs!

14. How do P and S-waves move?

Primary (compressional) waves
P-waves are the fastest waves created by an earthquake. They travel through the Earth's interior and can pass through both solid and molten rock. They shake the ground back and forth – like a Slinky – in their travel direction, but do little damage as they only move buildings up and down.

Secondary (shear) waves
S-waves lag behind P-waves as they travel 1.7 times slower and can only pass through solid rock. However they do more damage because they're bigger and shake the ground vertically *and* horizontally.

17. Do earthquakes happen off Earth?

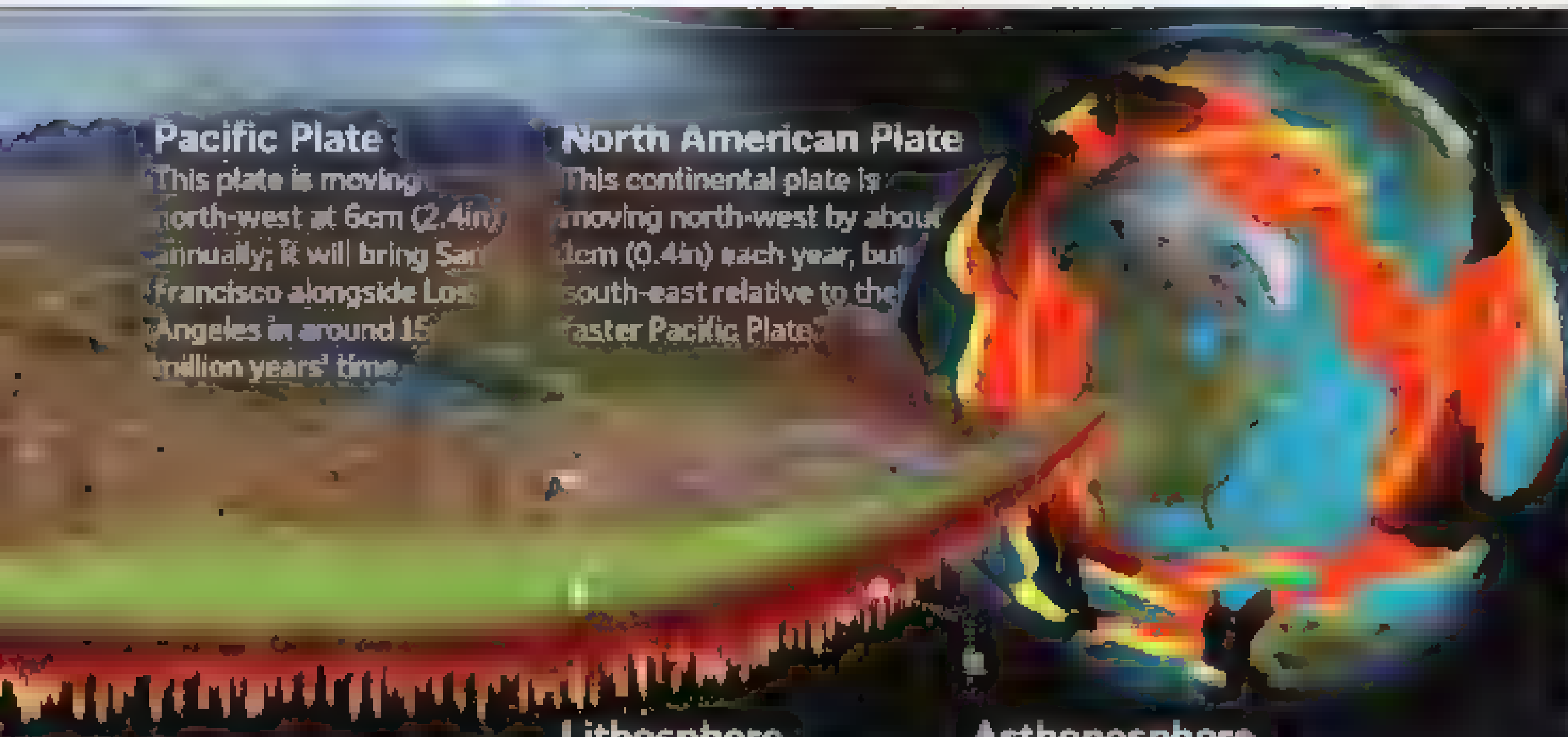
There's evidence of 'marsquakes' on Mars as well as quakes on Venus. Several moons of Jupiter and Titan – a moon of Saturn – also show signs of quakes. Seismometers on the Moon detected tidal 'moonquakes' caused by the pull of the Earth's gravity, vibrations from meteorite impacts and tremors caused by the Moon's cold crust warming after the two-week lunar night.

HEAD 2 HEAD
BIGGEST QUAKES

Shaanxi, China, 1556 (mag 8.0)
Around 830,000 people [illegible]

Tohoku, Japan, 2011 (mag 9.0)
Japan's biggest recorded earthquake killed 15,853 people, collapsed [illegible]

Valdivia, Chile, 1960 (mag 9.5)
The most powerful quake ever left 2 million people homeless and spawned a tsunami [illegible] Philippines



18. Why is the San Andreas Fault prone to large quakes?

Longer faults have larger earthquakes, which explains why the strike-slip San Andreas Fault has had several quakes over magnitude 7. The San Andreas Fault extends 1,300 kilometres (800 miles) along the coast of California. When a fault ruptures, it 'unzips' along its length. Each section of the fault releases energy – the longer the fault, the more energy released and so the bigger the quake. Scientists believe the San Andreas Fault is overdue for a potential magnitude 8.1 earthquake over a 547-kilometre (340-mile) length. The southern segment has stayed static for more than a century, allowing enormous stresses to build.

19. Could Africa ever be split from Europe by an earthquake?

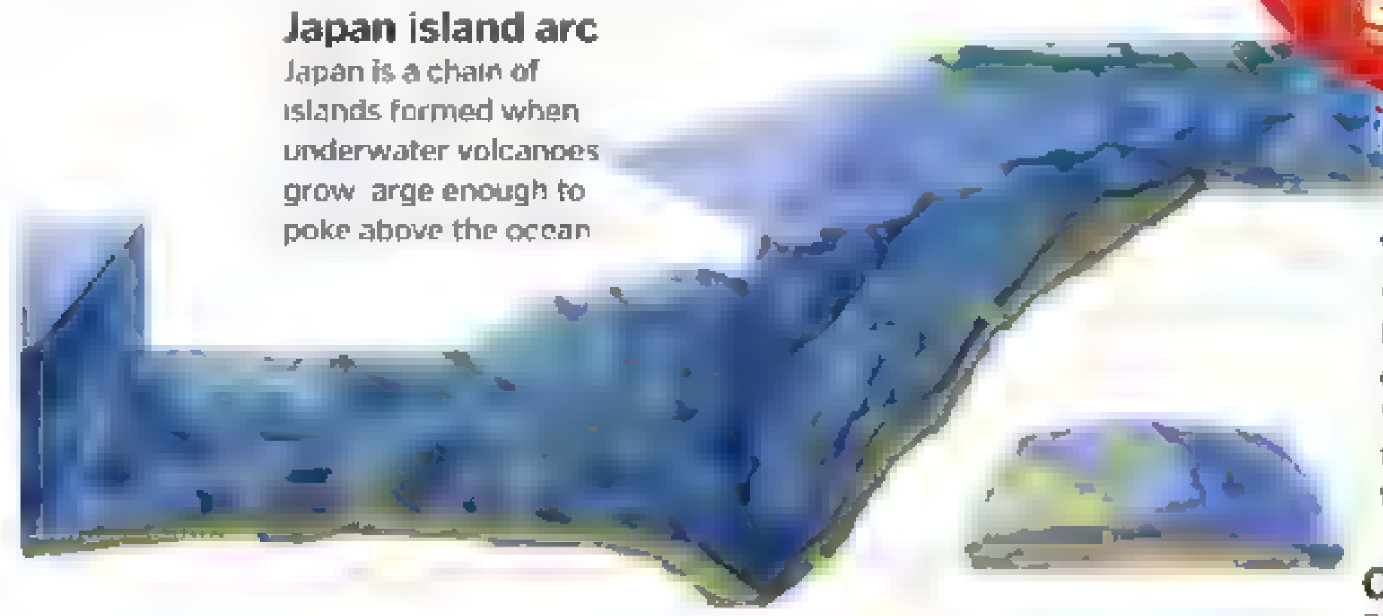
The Eurasian and African Plates are not splitting apart; they're actually moving towards each other at about one centimetre (0.4 inches) each year. In the future, it's possible that the Eurasian Plate may begin to slide beneath the African Plate. Even if the plates were moving apart, you'd need a mega-quake to yank Africa away from Europe in one go. There is no known fault long enough to create a mega-quake above magnitude 10. The most powerful earthquake in history was magnitude 9.5.

20. How many people jumping would it take to re-create the same reading as the Tohoku earthquake?

You'd need a million times Earth's population, all jumping at once, to generate the energy released by the March 2011 Tohoku quake. How do you calculate that? You assume Earth's population is 10 billion and each person generates 200 joules of energy by jumping 0.3 metres (0.98 feet).

21. How did the Japan Trench form?

A 390-kilometre (242-mile) stretch of the Japan Trench is associated with Japan's 2011 Tohoku earthquake. The trench is a vast chasm in Earth's crust at the junction between the Pacific Plate and tiny Okhotsk Plate beneath Japan. The Pacific Plate is moving westwards and diving beneath the Okhotsk. Friction between the two plates causes them to lock together and pressure to build. Sudden slippages release the tension in a violent burst of energy.



22. How long do quakes last?

10-30 secs

23 Can animals predict quakes?

[illegible]

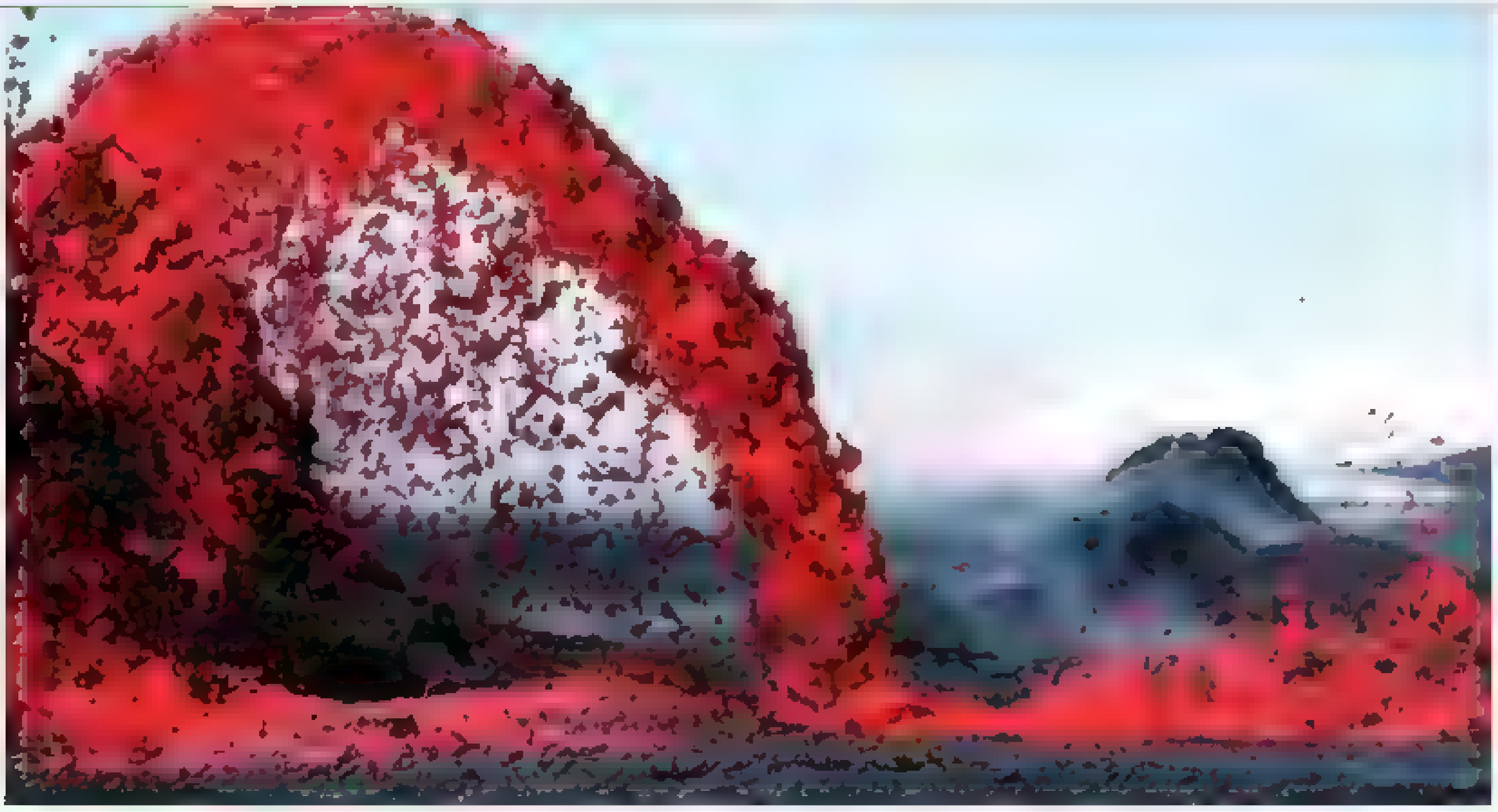
24 Where is the safest place to be during an earthquake?

[illegible]

25 If I were stood on a beach during an earthquake would I sink?

[illegible]

“Earth’s crust is made of three different types of rock – sedimentary, igneous and metamorphic”



Beneath the surface of the Earth

The composition and structure of the Earth is ever-changing. From crust to core, How It Works explores the materials, forces and phenomena that have allowed mere carbon to evolve into lifeforms and survive in the harshest of environments, the universe

Since the formation of the Earth over 4.5 billion years ago, it has continued to evolve at every level, with its physical make-up, atmosphere and physical forces locked in a permanent state of flux – creating, changing and destroying in equal measure. It was this ever-changing nature of its physical properties – that has continued over geological history – as well as the planet’s position in our solar system, that led to life appearing on its surface within its first billion years of existence, slowly generating a unique biosphere of organisms that now includes us.

Indeed, it is easy to underestimate how miraculous life’s existence is considering the planet’s position in the hostile environment of space. Extreme temperatures, continuous solar winds and massive solar radiation are but a selection of factors that the Earth is exposed to every second of every day. These are forces and energies that would, without the protective and generative forces of Earth, easily surpass the resistance threshold of organic life and make our very existence impossible.

Many of these processes emanate through activity undertook deep inside the Earth over its various layers. For example, rock formation – important for land-dwelling organisms – is generated through the volcanic activity of its upper mantle and the creative collisions and separations of the crust’s plate tectonics. Then there’s the generation of the Earth’s magnetic field in the electromagnetic liquid metal of the outer core – important for shielding the planet from solar winds and radiation – as well as massive heat generation from the super dense, as-hot-as-the-Sun inner core. All these processes and forces sustain life on Earth and secure our continued survival.

The Earth’s core is as hot as the surface of the Sun

5 TOP FACTS

Uniformitarianism
1 11th Century Persian scholar Avicenna proposed that the Earth's crust's rock formation occurs through processes that have operated uniformly throughout history.

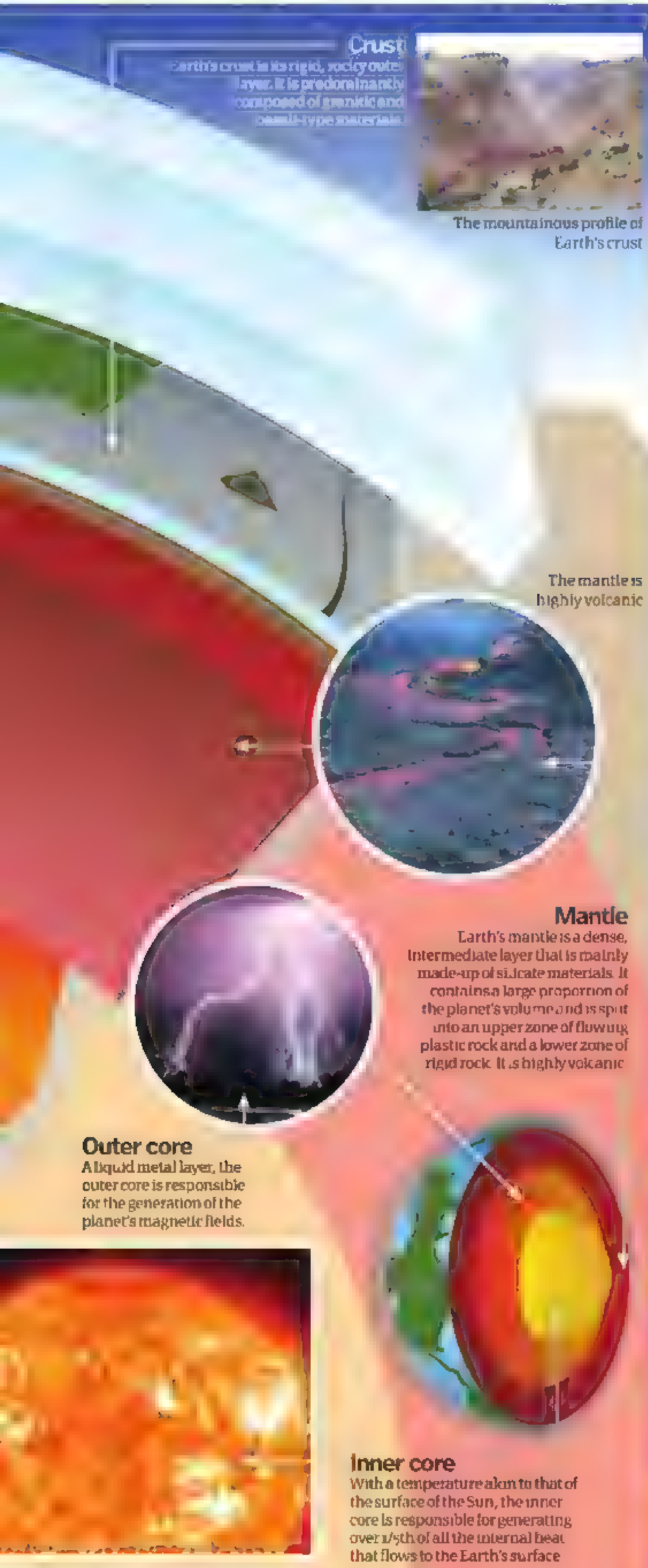
Causeway clash
2 In the late-18th Century two groups of scholars fought over how Giant's Causeway was formed, one believing from volcanic activity, the other sedimentary.

Ouroboros
3 It was geologist James Hutton who first raised the idea of the rock cycle, the process where rocks are eroded, compacted, compressed and melted before cooling into new rocks.

Tried and tested
4 Standard geological tools consist of a rock hammer, chisels, a pocket knife and a storage container. These tools have not really changed in over 400 years.

Creator
5 Volcanoes are one of the predominant creators of new rocks, formed from the cooling and crystallisation of magma. These rocks are igneous varieties.

There are three main rock types: igneous, sedimentary and metamorphic



CURRENT DEPTH: 0-50KM

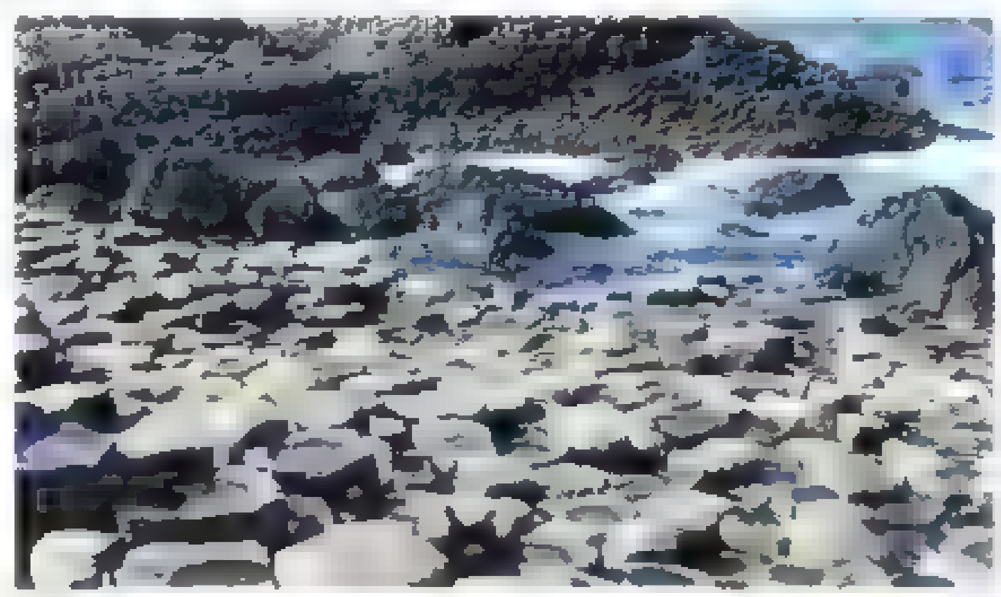
The Earth's crust and the formation cycle of rocks

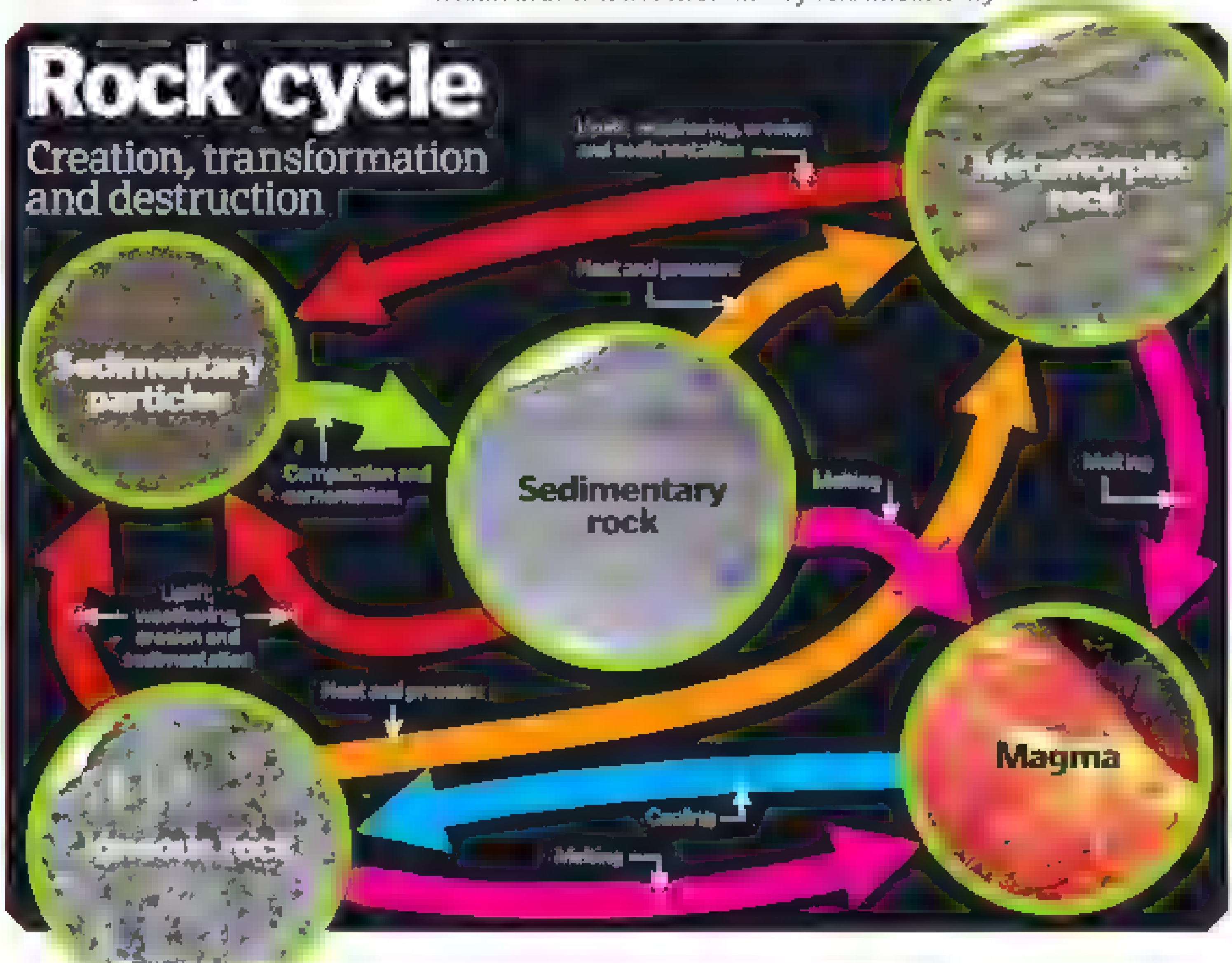
Extending from the surface to a depth of 50 kilometres, the Earth's crust is composed of low-density, easily transformed rocks

Earth's crust is made of three different types of rock – sedimentary, igneous and metamorphic – that undergo various dynamic transitions over geological time, altering the composition and appearance of surface terrain. These transitions are evidence of the rock cycle, a process of erosion, sedimentation, compaction and melting, which recycles all of Earth's rocks continuously. This process is possible as at the surface of the Earth, which is approximately 6,350 kilometres from the core, the density of rocks is low and they are easily changed when pushed from their environment of near-equilibrium.

For example, a sedimentary mountain face will be exposed over time to wind and rain, causing it to be eroded and broken down into particle form. These particles, carried downwards to the Earth's surface or deep into its crust through both caves and tunnels, will be dumped upon by fresh sediments, slowly burying them deep down into the planet. This compaction transforms the particles back into sedimentary rock that, under the pressure and increasing heat of the lower crust and mantle, is then either transformed into metamorphic rock or melted to form magma. If eventually transformed into magma, then once cooled it will reform as igneous rock.

Finally, regardless of type, the rock will be eventually melted and lifted back to the surface through the forces generated by the movements of plate tectonics and/or continental collision, ready to begin the cycle all over again.


Giant's Causeway in Northern Island, a fantastical formation of basalt rock caused by volcanic activity



"At 65.6km long, the Kazumura cave in Hawaii is currently the deepest primary cave network recorded"

CURRENT DEPTH: 0-100KM

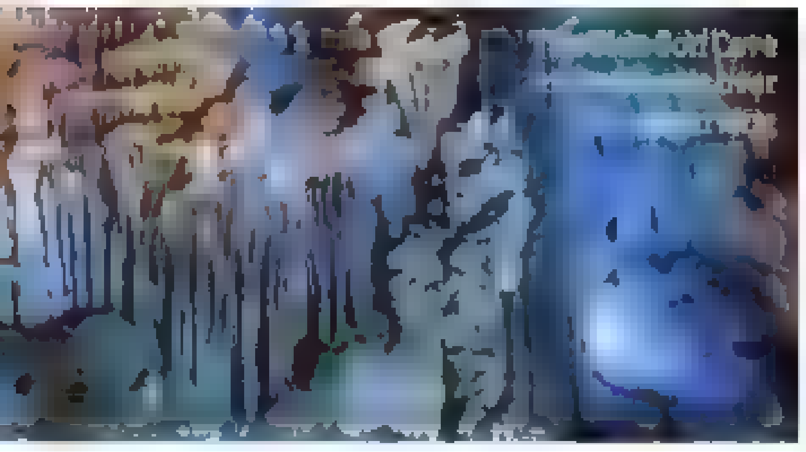
Caves and sub-terranean lakes

Beneath Earth's surface lie amazing structures that are a result of various geological processes

Leaving the surface of the Earth's crust and heading deeper underground, evidence of the planet's geological formation and processes at this outer layer are best shown in the caverns and subterranean lakes that lie within. Ranging from a few metres down to – in the case of Krubera-Voronja Cave in Georgia – multiple kilometres towards the Earth's core, our planet is littered with cavern networks leading down into the crust.

There are two main types of cave; solutional caves – which contain the majority of subterranean lakes – and primary caves. Solutional caves are formed when natural acids in groundwater seep down into the Earth's crust and dissolve any soluble, un-dense rocks such as limestone, chalk and dolomite. This results in a process of dissolution and depositation, where rocks are dissolved by a solvent and carried to a new position where they are deposited to form new rocks. When vast quantities of water build up on a cavern's floor, huge underground lakes form.

Primary caves are formed by volcanic activity, when magma cuts massive tubes and rifts into the rock, leaving caverns and tunnels that can stretch kilometres down into the Earth. As with solutional caves, the process of primary cave formation involves the melting of rocks and minerals in one place and carrying them to another position to reform. At 65.6km long, the Kazumura cave in Hawaii is currently the deepest recorded primary cave network in the world, stretching far into the Earth towards the bottom of the crust and mantle layer.



CURRENT DEPTH: 100-700KM

Earth's asthenosphere and plate tectonics

Plate tectonics tell us much about the movement of Earth's lithosphere

Earth's lithosphere – the crust and a portion of the underlying mantle – is broken up into multiple tectonic plates that float on and travel over the asthenosphere, a lower portion of the planet's mantle layer that begins roughly 100km down and ends approximately 700km towards the core. These plates move relative to each other at around 4-10cm per year and interact at their boundaries, generating volcanic activity, earthquakes and new terrain. Plate movement is possible because between the lithosphere and the asthenosphere boundary there is a plastic, partially molten zone of detachment.

Thanks to modern technology, NASA has been able to measure the rates of tectonic plate movement through radio telescopes, and predict what the Earth's land mass will look like in the future.

Transform
The San Andreas Fault is one of the Earth's most notable transform boundaries, with the Pacific and North American tectonic plates grinding past each other.

Subduction
Subduction boundaries occur when two plates push together and one dips under the other. The famous Pacific Ring of Fire is the result of numerous plates meeting.

Divergent
Thingvellir in Iceland marks the spot of a divergent (constructive) boundary, where the North American and Eurasian plates are moving slowly apart.

Convergent
One of the most famous examples of a convergent boundary, the Himalayas were created when the Indian and Eurasian plates ground into each other

THE STATS

LARGEST **Pacific** (103.3×10^6 km²) SMALLEST **S/American** (43.6×10^6 km²)

FASTEST **Oceanic** (52-69mm/yr) SLOWEST **Eurasian** (21mm/yr)

CURRENT DEPTH: 2,890-5,100KM

Earth's outer core and its magnetic fields

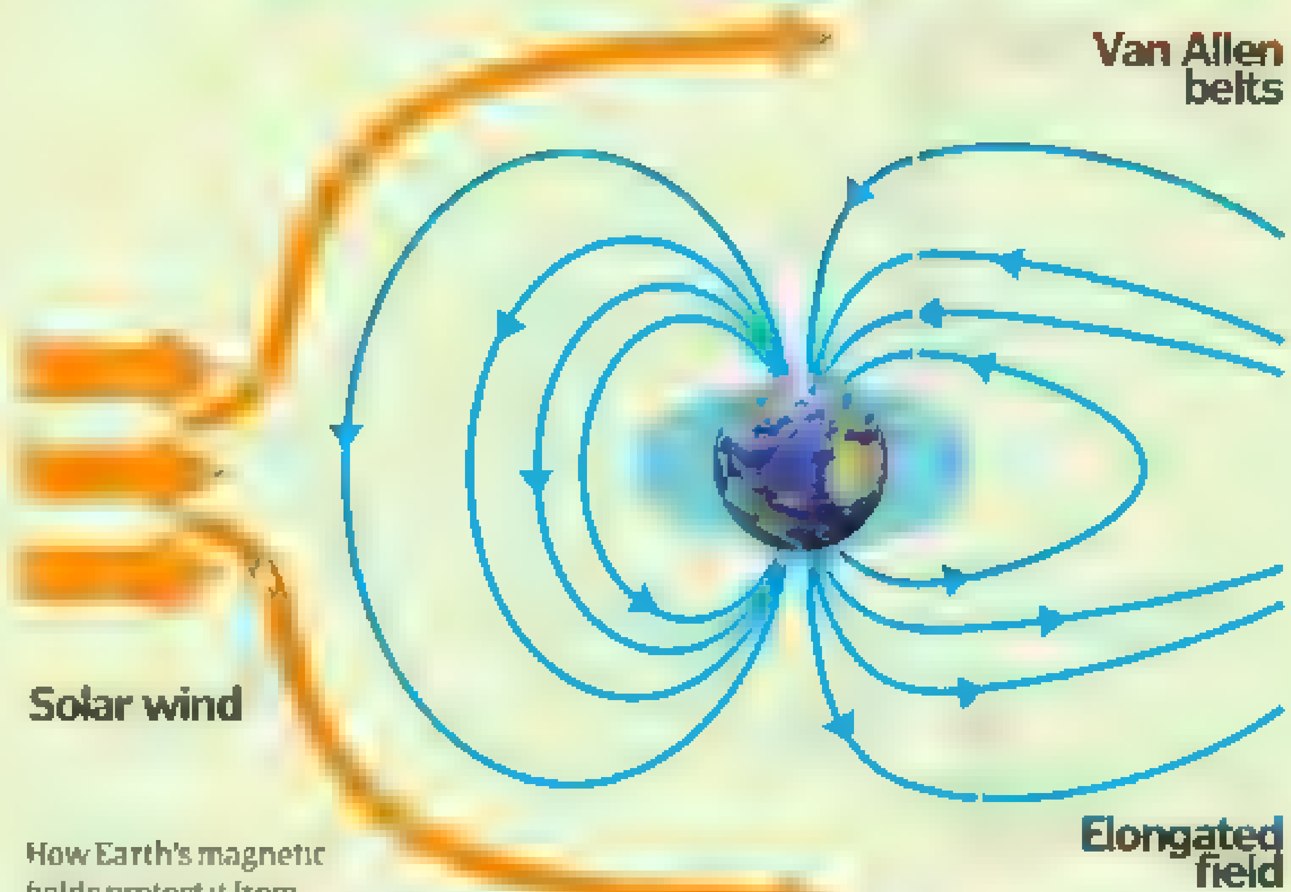
Earth's outer core comprises liquid metal

Our planet is surrounded by a magnetic field thanks to the motions of its outer core

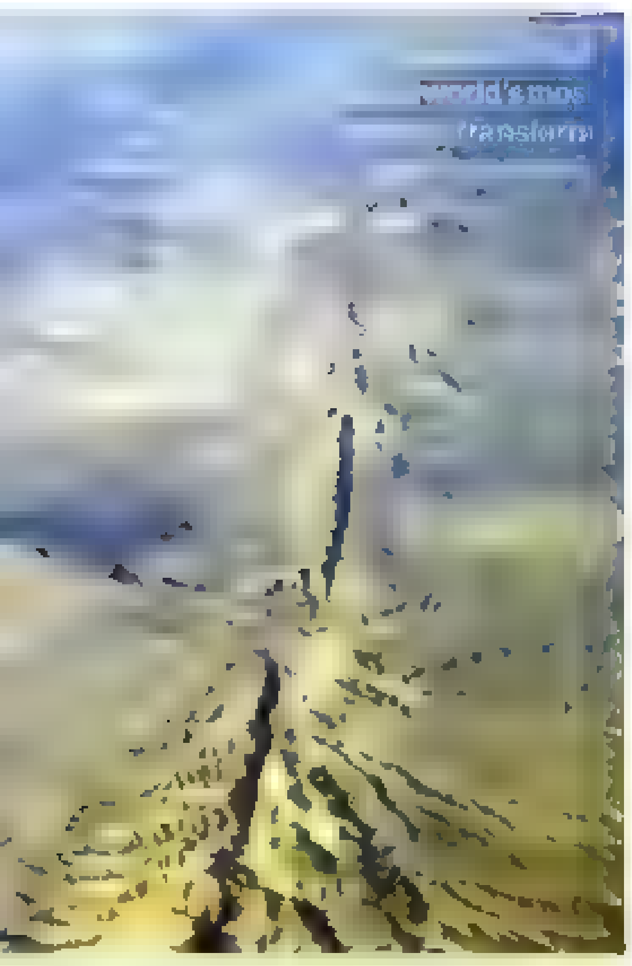
Beneath the Earth's mantle lies its outer core, an electrically conducting liquid layer of mainly iron and nickel that through helical motions generates an electromagnetic dynamo effect, giving rise to a geomagnetic field. Driven by the heat of the inner core, Earth's magnetic field permeates the planet – giving rise to surface magnetism – and a huge volume of space surrounding it, where it protects it from solar winds.

Due to the shifting nature of the outer core, the planet's magnetic north pole shifts position and occasionally flips completely, driven by turbulence in the liquid metals. When this field reversal occurs – which is infrequent and can range from a few hundreds of thousands of years to many millions – magnetic north ends up near the geographical South Pole in Antarctica.

The Earth's outer core extends for roughly 2,270 kilometres, beginning at the end of the mantle (2,890km down) and finishing at the start of the solid inner core (5,100km down). The outer core's radius is almost 3,500km, which is about the size of the entire of planet Mars, and the average temperature ranges between 6,700-8,500°F.



How Earth's magnetic fields protect it from solar winds



CURRENT DEPTH: 5,100-6,378KM

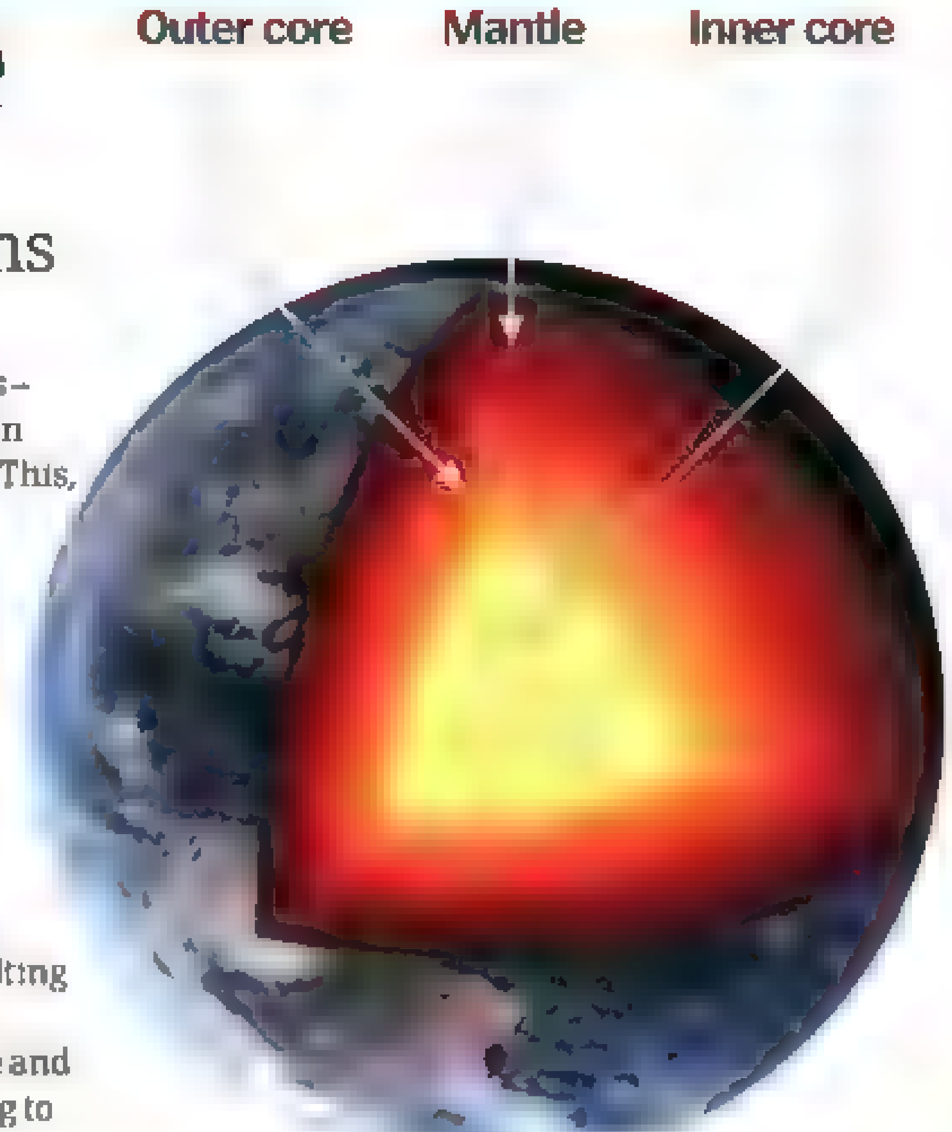
The inner core

Despite having a radius of only 1,220 kilometres, the Earth's inner core contains one third of the entire planet's mass

Beginning at the end of the Earth's outer core – at a depth of about 5,100km – the inner core is a super-dense, insanely hot sphere of iron, nickel, platinum, gold and other siderophile (iron-bonding) elements. The temperature here in the inner core is postulated to range between 8,500-12,100°F, which is comparable to the surface of the Sun. Indeed, scientists estimate that roughly 1/5 of all internal heat that flows to the surface of the Earth emanates from the core's central reservoir and that it is also a key player in sustaining the Earth's magnetic fields.

According to research released in the last five years, the inner core spins at a faster rate than the rest of the planet – between an extra 0.3 to 0.5 degrees – completing an entire extra full spin over a period of 700 to 1,200 years. This, it has been suggested, is due to electric and magnetic fields generated in the outer core pushing on the metallic inner core, driving it like a rotor.

The iron richness of the inner core is the result of planetary differentiation, a process where in the early stages of a planet's formation the extreme heat of the environment would cause the melting of all substances, with the denser ones sinking down into the centre and the less-dense materials migrating to the crust.



Mega tsunami

Among the most epically destructive forces on Earth, tsunamis cause catastrophic levels of carnage, unearthing trees, levelling buildings and ending life. How It Works delves to the bottom of the ocean to track and explain their causes and formation

Tsunamis form through a complex, multi-stage process that emanates from the massive energy release of a submarine earthquake, underwater or coastal landslide, or volcanic eruption.

The first stage in this formation begins when the tectonic upthrust caused by the quake or impulse event causes massive amounts of ocean water to be displaced almost instantaneously. This action kick-starts a simple series of progressive and oscillatory waves that travel out from the event's epicentre in ever-widening circles throughout the deep ocean. Due to severe levels of energy propagated from the impulse, the waves build in speed very quickly, reaching up to an incredible 500mph. However, due to the depth of water, the speed of the waves is not visible as they expand to have incredibly long wavelengths that can stretch between 60-120 miles. Because of this, the wave amplitudes (the wave height) are also very small as the wave is extremely spread out, only typically measuring 30-60 centimetres. These long periods between wave crests – coupled with their very low amplitude – also mean that they are particularly difficult to detect when out at sea.

Once generated, the tsunami's waves then continue to build in speed and force before finally approaching a landmass. Here the depth of the ocean slowly begins to reduce as the land begins to slope up towards the coastline. This sloping of the seabed acts as a braking mechanism for the high-velocity tsunami waves, reducing their speed through colossal friction between the water and the rising earth. This dramatic reduction in speed – which typically takes the velocity of the

5 TOP FACTS TSUNAMI

Harbour wave
1 In Japanese the word tsunami literally translates as 'harbour wave'. Tsunamis are a frequent occurrence in Japan, with over 195 recorded throughout history so far.

Ancients
2 It was the Greek historian Thucydides who first linked tsunamis to earthquakes. However, their exact cause remained speculative until the 20th Century.

Brakes
3 Out at sea tsunamis travel incredibly quickly, often clocking up over 500mph. This speed slows as it reaches the shoreline, often being reduced to around 50mph.

Quick draw
4 The first part of a tsunami to reach land is referred to as a 'trough'. Here water along the shore recedes dramatically in a mass drawback, exposing normally submerged areas.

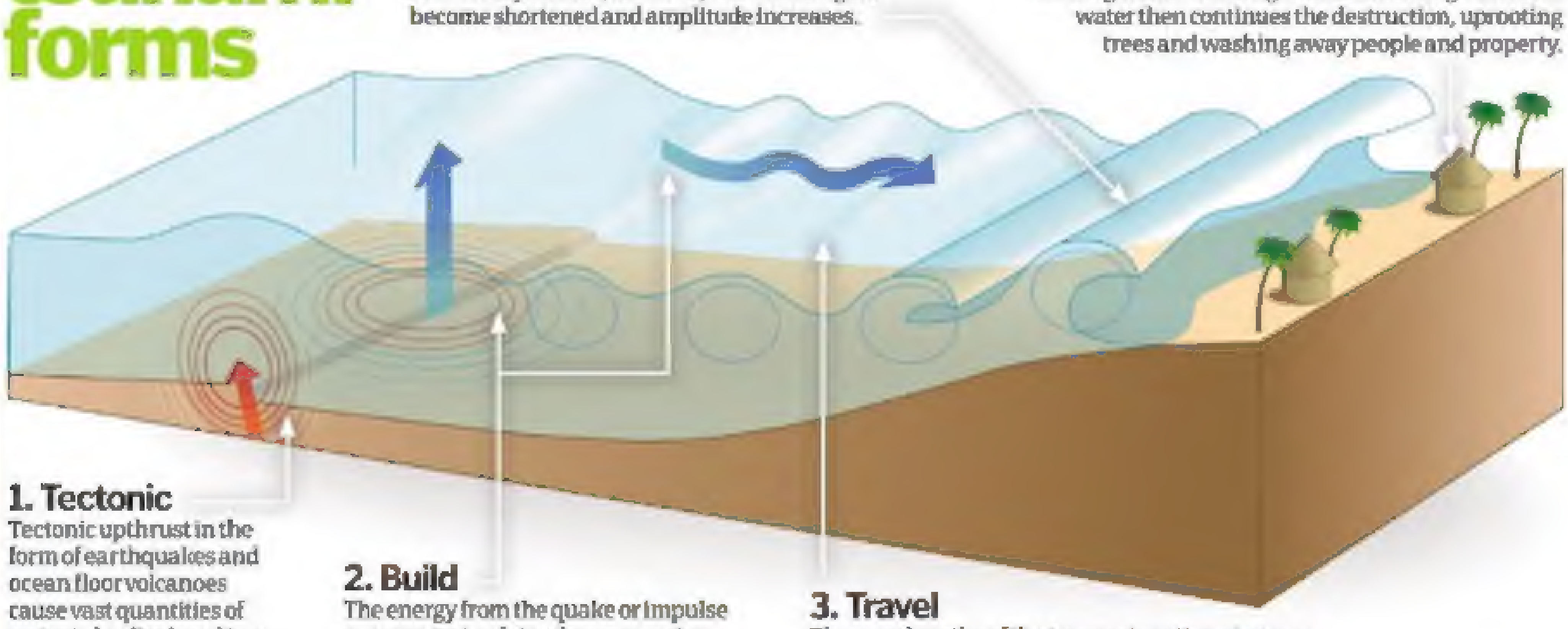
Monitoring
5 Due to their destructive nature, tsunami-related activity is monitored by specialist observation centres such as the Pacific Tsunami Warning Center in Honolulu.

DID YOU KNOW? The earthquake that generated the 2004 Indian Ocean tsunami was the fifth most deadly in history

How a tsunami forms

4. Approach
As the tsunami waves approach the coastline of a landmass they are slowed dramatically by the friction of their collision with the rising seabed. As the velocity lessens, however, the wavelengths become shortened and amplitude increases.

5. Impact
Finally, with the wavelength compressed and heightened to large levels (often between five and ten metres), the giant waves collide with the shore causing massive damage. The succeeding outflow of water then continues the destruction, uprooting trees and washing away people and property.



1. Tectonic
Tectonic upthrust in the form of earthquakes and ocean floor volcanoes cause vast quantities of water to be displaced in a very short space of time, generating a massive amount of energy.

2. Build
The energy from the quake or impulse causes a train of simple, progressive oscillatory waves to propagate over the ocean surface in ever-widening circles at speeds as fast as 500mph.

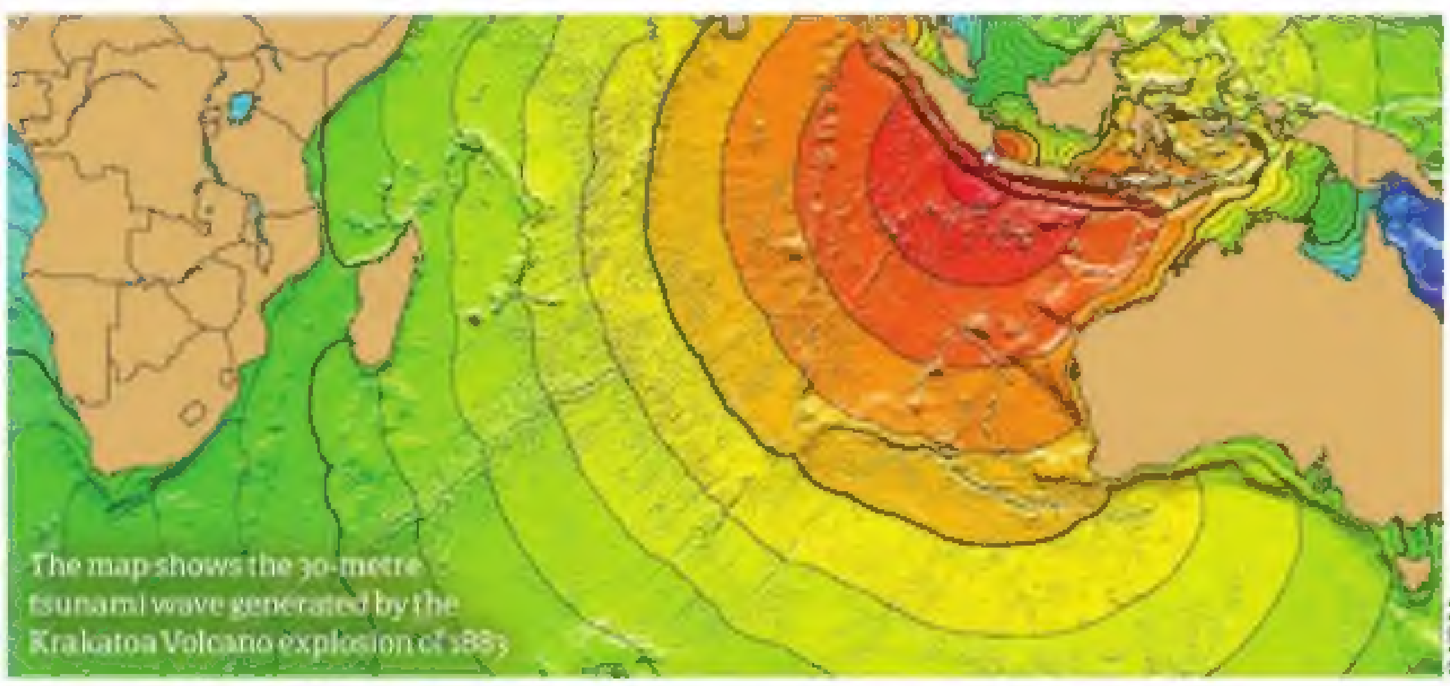
3. Travel
The wavelengths of the tsunami continue to grow, with the waves' periods (the lengths of time for successive crests or troughs to pass a single point) varying from five minutes to more than an hour.

© Science Photo Library

Cause
Tsunamis initiate when an earthquake causes the seabed to rupture (bottom centre), which leads to a rapid decrease in sea surface height directly above it.

© Science Photo Library

Effect
As the tsunami reaches the shore the shallow, long and exceedingly fast waves pile up, reducing the wavelength and increasing their height dramatically.



The map shows the 30-metre tsunami wave generated by the Krakatoa Volcano explosion of 1883

© NOAA

No need to ask what this sign means

tsunami to 1/10th of its original speed – also has the effect of reducing the length of its waves, bunching them up and increasing their amplitude significantly. Indeed, at this point coastal waters can be forced to raise as much as 30 metres above normal sea level in little over ten minutes.

Following this rise in sea level above the continental shelf (a shallow submarine terrace of continental crust that forms at the edge of a continental landmass) the oscillatory motions carried by the tsunami are transferred into its waters, being compressed in the process. These oscillations under the pressure of the approaching water are then forced forwards towards the coast, causing a series of low level but incredibly fast run-ups of sea water, capable of propelling and dragging cars, trees, buildings and people over great distances. In fact, these run-ups are often responsible for a large proportion of the tsunami's damage, not the giant following waves. Regardless, however, following the run-ups the tsunami's high-amplitude waves continue to slow and bunch into fewer and fewer megawaves before breaking at heights between five and ten metres over the immediate coastline, causing great damage and finally releasing its stored energy.

Due to the severe hazards that tsunamis pose, research into their ▶

Head to Head
HISTORIC TSUNAMIS

BIG

1. Messina
The Messina earthquake of 1908 triggered a large tsunami 12 metres high that levelled entire buildings and killed more than 70,000 people in Sicily and southern Italy. The earthquake that generated it measured 7.5 on the Richter scale and caused the ground to shake for between 30 and 40 seconds.

BIGGER

© Science Photo Library

2. The Valdivia earthquake
The Valdivia earthquake of 1960 caused one of the most damaging tsunamis of the 20th Century. Thousands of people were killed by it and it stretched as far as Hilo, Hawaii. Measuring 9.5 on the Richter scale, the earthquake caused waves up to 25 metres to assault the Chilean coast. The earthquake also triggered landslides and volcanic eruptions.

BIGGEST

3. Lituya Bay
After an earthquake caused a landslide at the head of Lituya Bay, Alaska, in July 1958, a massive tsunami was generated measuring over 524 metres in height, taller than the Empire State Building. Amazingly, despite the awesome height of the tsunami, only two fishermen operating in the bay were killed by it.

"Due to severe levels of energy propagated from the impulse, the waves build in speed very quickly"

causes and tracking of their formation has increased through the 20th and 21st Centuries. Currently, the world's oceans are monitored by various tsunami detection and prevention centres, such as the NOAA (National Oceanic and Atmospheric Administration) run Pacific Tsunami Warning Center (PTWC) based in Honolulu, Hawaii.

Set up back in 1949, the PTWC utilises a series of tsunami monitoring systems that delivers seismic and oceanographic data to it on a daily basis, with information transferred to it and other stations by satellite connection. This is one of two American-run centres that monitors the Pacific Ocean and it is responsible for detecting and predicting the size and target of any approaching tsunamis.

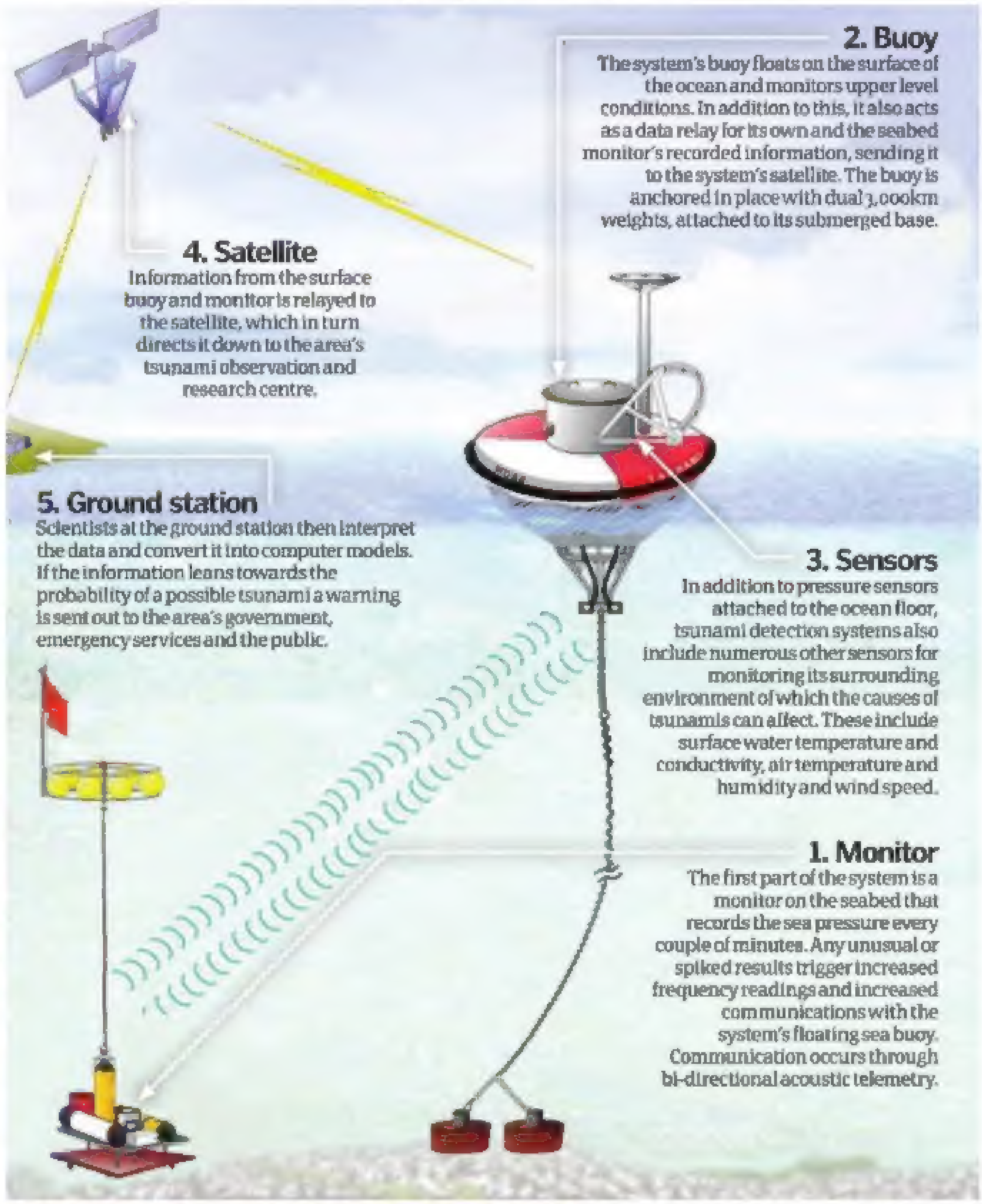
Tsunami prevention has also seen advances as construction techniques and materials have developed over the past century. Now areas that are prone to tsunamis, such as Japan's west coast, are fitted with large-scale sea walls, artificial deep-sea barriers, emergency raised evacuation platforms and integrated electronic warning signs and klaxons in coastal resorts and ports.

Areas that have been affected by tsunamis in the past are also fitted with physical warning signs and have specific evacuation routes that best allow for large numbers of people to quickly move inland. Unfortunately, however, despite many advances being made to ensure prone areas are protected and warned in advance, due to the transcontinental nature of generated tsunamis, remote or under-developed areas are still affected regularly, the consequences of which have been recently shown in the disastrous 2004 tsunami in the Indian Ocean that claimed over 200,000 lives.

A tsunami early-detection buoy is removed from the ocean for maintenance

The DART II tsunami detection system

Introducing the system and technology that aids scientists in detecting upcoming tsunamis



The devastated Marina beach in Chennai after the Indian Ocean tsunami struck

A tsunami emergency evacuation platform in Japan

THE STATS 2004 INDIAN OCEAN TSUNAMI

HEIGHT 30m DEATHS 230,000 MONEY RAISED $7bn

COUNTRIES AFFECTED 14 EARTHQUAKE MAGNITUDE 9.3

DID YOU KNOW? *The 2004 tsunami released 1,502 times the energy of the Hiroshima atomic bomb*

The 2004 Indian Ocean tsunami

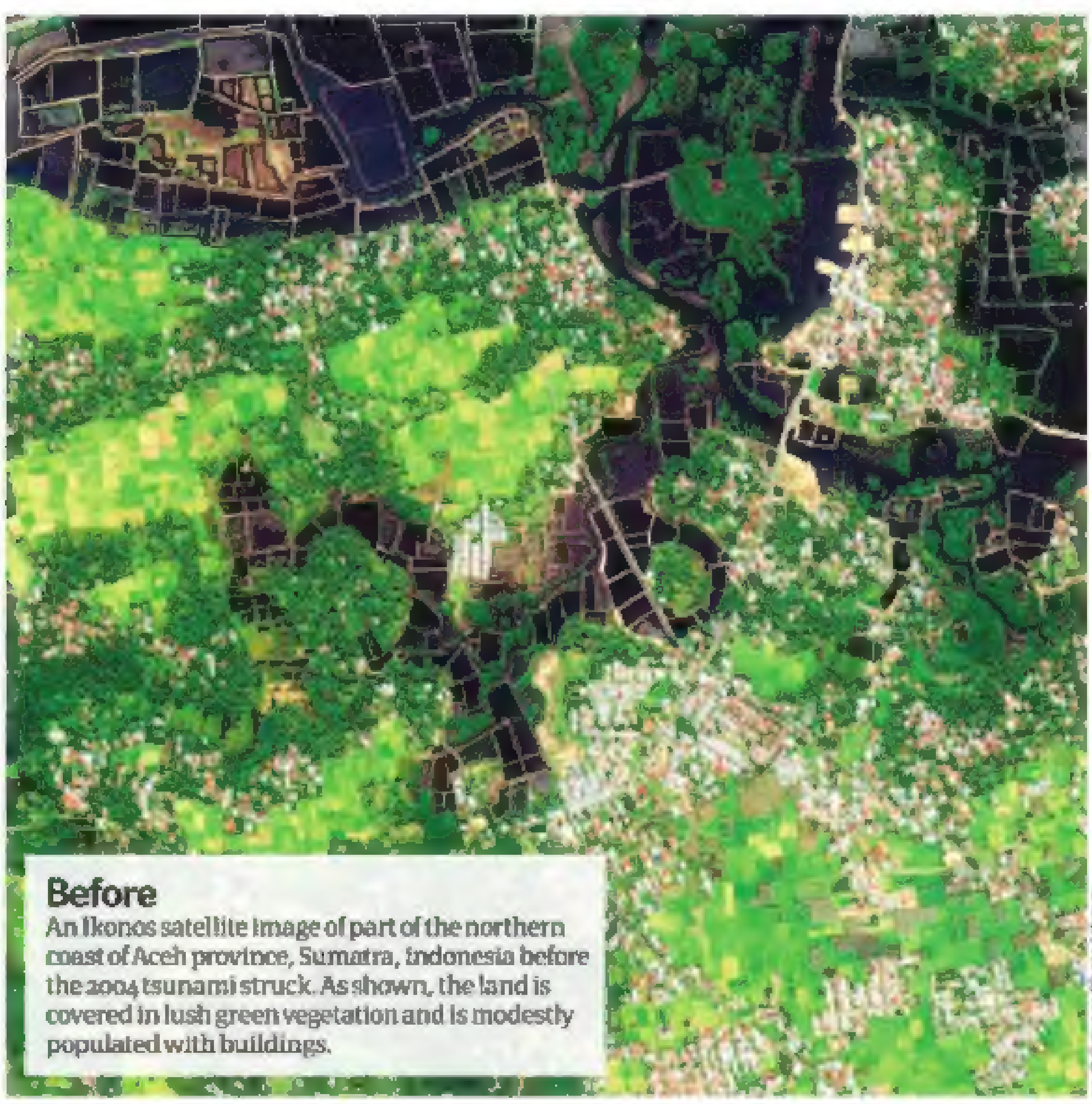
Claiming the lives of over 200,000 people, the Indian Ocean tsunami of 2004 was literally off-the-scale in terms of both damage and destruction

The 2004 tsunami striking the coast of Thailand

On 26 December 2004, an undersea megathrust earthquake caused a huge earth subduction and triggered a series of devastating tsunamis that ravaged almost all landmasses bordering on the Indian Ocean, killing over 230,000 people in 14 different countries. The hypocentre of the main earthquake was approximately 100 miles off the western coast of northern Sumatra and emanated from the ocean floor 19 miles below the area's mean sea level. Here, a massive rupture in the ocean floor caused massive tectonic plate movement – an event felt as far away as Singapore – as well as the creation of numerous secondary faults that elevated the height and speed of generated waves to titanic levels.

The fallout from the earthquake and resulting tsunami was the worst for over 50 years, with the event releasing a total of 1.1×10^{7} joules of energy. This level of energy release was comparable to 26.3 megatons of TNT, over 1,502 times the energy released by the Hiroshima atomic bomb. Indeed, the rupture was so severe that the massive release of energy was so great it slightly altered the Earth's rotation, causing it to wobble on its axis by up to 2.5cm.

Further, when the British Royal Navy vessel HMS Scott surveyed the seabed around the earthquake zone with a multi-beam sonar system, it revealed that it has drastically altered its topography. The event has caused 1,500m ridges to collapse into massive landslides kilometres long. The momentum of the water displaced by tectonic upshift had also dragged massive million-ton rocks over 10km on the seabed and an entirely new oceanic trench had been exposed.



Before
An Ikonos satellite image of part of the northern coast of Aceh province, Sumatra, Indonesia before the 2004 tsunami struck. As shown, the land is covered in lush green vegetation and is modestly populated with buildings.

After
An Ikonos satellite taken on 29 December 2004, three days after the tsunami struck. As can be seen now, almost all of the immediate coastline has been completed submerged underwater and the huge, lush plains of vegetation have been severely encroached upon and washed away. Many buildings have also been submerged or destroyed.